AMRL-TR-65-182

FACTORS AFFECTING SURVIVAL DURING PROLONGED HYPOTHERMIA

E. T. ANGELAKOS, MD, PhD

BOSTON UNIVERSITY SCHOOL OF MEDICINE

DECEMBER 1965

AEROSPACE MEDICAL RESEARCH LABORATORIES
AEROSPACE MEDICAL DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

NOTICES

When US Government drawings, specifications, or other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever, and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise, as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Requests for copies of this report should be directed to either of the addressees listed below, as applicable:

Federal Government agencies and their contractors registered with Defense Documentation Center (DDC):

DDC
Cameron Station
Alexandria, Virginia 22314

Non-DDC users (stock quantities are available for sale from):

Chief, Input Section
Clearinghouse for Federal Scientific & Technical Information (CFSTI)
Sills Building
5285 Port Royal Road
Springfield, Virginia 22151

Change of Address

Organizations and individuals receiving reports via the Aerospace Medical Research Laboratories' automatic mailing lists should submit the addressograph plate stamp on the report envelope or refer to the code number when corresponding about change of address or cancellation.

Do not return this copy. Retain or destroy.

The experiments reported herein were conducted according to the "Principles of Laboratory Animal Care" established by the National Society for Medical Research.

500 - February 1966 - 773-32-665

Approved For Release 2002/11/08 : CIA-RDP75B00285R000100050001-5

FACTORS AFFECTING SURVIVAL DURING PROLONGED HYPOTHERMIA

E. T. ANGELAKOS, MD, PhD

Approved For Release 2002/11/08 : CIA-RDP75B00285R000100050001-5

FOREWORD

This study was initiated by the Biomedical Laboratory of the Aerospace Medical Research Laboratories, Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio. The research was conducted in the Hypothermia Laboratory at the Department of Physiology of Boston University School of Medicine under Contract No. AF 33(657)-10755. Dr. E.T. Angelakos was the principal investigator for Boston University School of Medicine. Mr. J.F. Hall, Jr., Chief of the Biothermal Branch, was the contract monitor for the Aerospace Medical Research Laboratories. The work was begun in support of Project No. 7222 "Biophysics in Flight" and Task No. 722204 "Human Thermal Stress in Extended Environment" and was continued under Project No. 7164 "Biomedical Criteria for Aerospace Flight" and Task No. 716409 "Human Thermal Stress." This report covers research performed between February 1963 and April 1965.

This technical report has been reviewed and is approved.

WAYNE H. McCANDLESS
Technical Director
Biomedical Laboratory
Aerospace Medical Research Laboratories

ABSTRACT

The mortality of anesthetized dogs maintained under prolonged hypothermia was studied and the factors responsible for death were evaluated. In the technically acceptable experiments, 45% of the dogs maintained at moderate hypothermic temperatures (26° ± 1° C) died within 16 hours. The corresponding mortality in normothermic (38° C) control dogs was 7%. Progressive hemoconcentration and bradycardia were observed during prolonged hypothermia. The former could be abolished by splenectomy. The use of artificial pacemakers to limit the effects of bradycardia was unsuccessful due to the development of other cardiovascular complications. Blood catecholamine levels increased with cooling to 33° C but decreased below control levels at or below 25° C; however, prolonged hypothermia at 25° C was associated with a progressive increase in blood catecholamines up to two to three times the initial control levels. The catecholamine content of aorta, kidney and spleen was not altered significantly by hypothermia, however, cardiac catecholamines decreased to below 50% of control with cooling to 25° C. Adrenergic mechanisms apparently play a key role in the alterations of cardiovascular functions which limit survival during prolonged hypothermia.

TABLE OF CONTENTS

I INTRODUCTION

The aim of this series of studies which were begun in 1961 (1)* was to study the various factors that affect survival under prolonged hypothermia. Initial experience indicated that such experiments are generally complicated by a variety of technical difficulties associated with the maintenance of anesthetized hypothermic animals over prolonged periods of time under laboratory conditions. As a result, in most cases, only a fraction of the experiments performed were technically successful. Similar experiences have been reported by others (see below).

The previous studies made in this laboratory indicated that a decrease in the cardiac pacemaker rate, progressive hemoconcentration and possibly a water shift out of the intravascular compartment observed during prolonged hypothermia, could be responsible for the progressive deterioration and death. The present studies were designed to confirm and extend these findings and to inquire further on other factors that may contribute to the progressive functional deterioration under prolonged hypothermia.

In the present Technical Report, results are presented from studies on: a) Control normothermic preparations, b) functional spleenectomy, c) electrical pacing of the atrium and ventricle and d) the status of the adrenergic system as shown by tissue and plasma levels of catecholamines.

II LITERATURE REVIEW

Previous studies made in this laboratory indicated that animals maintained at moderate hypothermic temperatures for several hours show a progressive deterioration and death (1). Nearly 50% of the animals died when body temperatures were maintained at 26 ± 1°C for 18 hours. In addition, prolonged hypothermia was found to be associated with hemoconcentration, bradycardia, acidosis, and possible alterations in plasma volume.

* See reference section at end of report.

Similar results have been reported by others. A similar incidence of death in the dog maintained at low temperatures has been reported by Spurr, Hutt and Horvath (2). Popovic (3) reported a hemoconcentration during prolonged hypothermia in the rat; the blood hematocrit and hemoglobin concentrations were found to increase progressively with the duration of hypothermia. The same author (4) reported that rats maintained at body temperatures of 15°C for more than six hours showed an "irreversible" hemoconcentration. In addition, under the experimental conditions used in these experiments, there was also a hyperglycemia and acidosis without any progressive changes in heart rate. This last observation is at variance with our results in the dog (1) and apparently reflects a species difference. However, others have reported a further decrease in heart rate with prolonged hypothermia in the rat (5). Connaughton, Holt and Lewis (6) studied the effect of prolonged hypothermia at temperatures between 22-24°C. A hemoconcentration was again observed by these workers. The hematocrit values reported are similar to the results obtained in our laboratory. In addition, Connaughton et al. (6) reported a progressive decrease in blood pressure, heart rate, plasma volume and blood pH. All of these observations are in essential agreement with our findings. More recently, the same group studied the effect of prolonged hypothermia in the rat (5). They reported hemoconcentration and overall mortality similar to that observed in the dog.

At the time when the present project was begun (early 1963), the consensus was that prolonged hypothermia produces distinct alterations in cardiovascular dynamics over and above what is observed during the acute phase. These alterations were found to be associated with the high mortality observed during prolonged hypothermia, presumably through the development of irreversible states. However, the specific factors that were involved remained obscure.

At this writing (late 1964), the state of knowledge in this area has not changed substantially, i.e., the factors which affect survival during prolonged hypothermia remain largely unknown. Yet the need for further information on

this subject is increasing. Apart from the possible application of such information to increasing survival after accidental hypothermia, there are speculations of the possible use of prolonged hypothermia in such important military areas as space travel and protection from radiation as well as in a number of clinical conditions including treatment of strokes, cardiac tachycardias, cancer, and in the transplantation of organs. The possible application of hypothermia to space travel has been discussed some years ago by Hock (7).

III GENERAL METHODS

All studies were made on mongrel dogs anesthetized with pentobarbital (33 mg/kg). A total of over 120 dogs were studied but the technically acceptable experiments were limited to 80 dogs. In the hypothermic experiments, the animals were cooled by being enclosed in a "hypothermic blanket" (Thermo-O-Rite Products, Inc.) through which a cooling fluid was circulated. In general, cooling was first induced rapidly at 28°C, then the animals were stabilized at the desired temperature and/or cooled further. In the experiments with control normothermic animals the body temperature was maintained at normothermic levels during anesthesia by circulating warm (38°C) water through the "hypothermic blanket".

Body temperature was measured from a thermistor probe inserted in the esophagus at the level of the heart. Blood pressure was measured through a short catheter inserted into the carotid and connected to a strain gauge. In general, records of blood pressure and ECG were made on a two-channel recorder. In many cases, a two-channel FM instrumentation tape recorder was used. This permitted subsequent reviewing of the experimental recording with an 1:8 time reduction factor. Continuous oscilloscope monitoring of blood pressure, ECG and/or other parameters was routinely made.

Further details of the special methodology used in specific experiments is given in each section.

IV RESULTS

A. Control Normothermic Preparations

In the previously reported studies (2), it was found to be technically difficult to maintain a series of animals at normothermic temperatures for a prolonged period of time in order to compare the results obtained with animals maintained under hypothermia over the same period. These difficulties were mainly associated with control of anesthesia and body temperature. These difficulties were largely eliminated in the present studies by the use of the "hypothermic blanket" with 38°C water circulating through it, and a constant infusion of pentobarbital 2-5 mg/Kg/hr. Artificial respiration was also employed. Results from 15 normothermic animals maintained over a period of 15 to 21 hours are shown in Table 1 together with a series of 20 hypothermic animals maintained over the same period.

Table 1. Mortality of control normothermic and hypothermic animals maintained for a period of 16 hours.

	No. of Dogs	% Mortality	P*
Control (38°C)	15	7	--
Hypothermic (26 ± 1°C)	20	45	0.015

*Fisher "exact test". Statistically significant when $P < 0.05$.

Among the technically acceptable experiments where anesthesia and body temperature were maintained at desirable levels, only one out of 15 normothermic animals died. The exact cause of death could not be determined in this case but was associated with progressive hypotension and shock. Attempts were made to maintain a total of 20 normothermic animals. Of the five eliminated from the series (not included in Table 1) one died from excessive infusions of anesthetic, and four were not maintained at normothermic temperatures and became progressively hypothermic. No hypothermic animals were omitted from this series.

Even if the entire mortality of 2 out of 20 (10%) of the controls is considered, the mortality of the hypothermic animals is considerably higher. Using the Fisher "exact test", the difference shown in Table 1 is statistically significant at the 5% level ($P < 0.05$). A similar conclusion is reached when the entire control mortality (2 out of 20) is considered. In the latter case the exact probability for the null hypothesis is $P = 0.02$ and hence the difference is statistically significant at the 5% level ($P < 0.05$).

Complete serial hematocrit values were obtained in 9 normothermic and 7 hypothermic animals for the first 8 hours and the results are presented in Table 2.

Table 2. Blood hematocrit in anesthetized dogs maintained for 8 hours in normothermia or hypothermia.

Normothermic 38 ± 1°C			Hypothermic 26 ± 1°C		
Control	4 hrs	8 hrs	Control	26°C	8 hrs
40	45	45	40	45	65
44	47	49	42	47	51
46	45	45	38	52	59
30	43	41	41	57	73
49	46	46	32	44	51
30	34	37	35	41	36
38	48	48	44	54	64
48	50	51			
38	44	50			
		means			
40	45	46	39	49	57

There were no consistent changes in the heart rate of normothermic animals. However, some variation around the control range was noted which was apparently related to variations in the level of anesthesia. The hypothermic animals showed a progressive decrease in heart rate while being maintained at 26 ± 1°C as previously described (1). However, careful

examination of the changes in heart rate over the entire period revealed that in certain animals there was a rather abrupt decrease in heart rate at some point during this period. For instance, the heart rate of one animal changed from 90 beats per minute to 55 beats per minute within 15 minutes between 6 and 6¼ hours after stabilization at 25°C. The rate then decreased to 38 beats per minute in the next fifteen minutes and was maintained near this level for several hours thereafter. Similar observations were made in 2 other animals. ECG records during this time revealed no obvious change of the pacemaker site. Unfortunately these records had to be made at very slow speeds and, therefore, could not show minor changes in the pacemaker site. Thus the interpretation of this observation remains open.

B. Functional Splenectomy

Ligation of the splenic pedicle was performed in four dogs prior to cooling. Hematocrit measurements were made during subsequent cooling to 25°C and while maintaining the animals for several hours at this hypothermic temperature. Results from two dogs for which extensive data were available are shown in Table 3.

Table 3. Hematocrit values in two splenectomized dogs cooled to 25°C and maintained at that temperature.

Temp. °C	Hours at 25°C	Dog #1	Dog #2
38		46	39
33	-	46	40
30	-	46	41
27	-	45	41
25	0	45	42
25	2	46	42
25	3	46	42
25	5	47	43
25	6	47	--

They both show only a minor change in hematocrit, less than 5%, while cooling and maintained under hypothermia. The other two animals, for which only initial and terminal values were available, again showed no significant change in hematocrit. The observed changes were very small compared to those observed in non-splenectomized hypothermic animals, and are not different from those observed in normothermic controls (Table 2). If these limited results reflect a general phenomenon, it would appear that the participation of the splenic pool of red blood cells is essential for the development of the hemoconcentration observed during acute and prolonged hypothermia. This could be brought about by splenic contraction producing a release of red blood cells in the general circulation.

However, a more complex circulatory readjustment may be involved. This is suggested by the results on splenic weight obtained in connection with another study (see Section D). When the weights of the spleens of six hypothermic dogs were compared with those from a similar group of dogs maintained at normothermia over the same period of time, it was found that the spleens of the hypothermic group were, on the average, heavier than those of the normothermic animals. The pertinent data are given in Table 4.

Table 4. Spleen weight (gms) in six hypothermic (25°C) and six normothermic control dogs (values are tabulated ranked within each group).

Rank	Normothermic Controls	Hypothermic 25°C
	wt. in gms.	
1.	17.4	32.3
2.	28.1	42.1
3.	34.1	43.9
4.	38.2	49.1
5.	44.2	49.4
6.	53.4	71.1
mean	36.0	48.0

It should be noted that in both groups there was a large variation in the splenic weights. This problem therefore requires reinvestigation in a larger series of animals.

In any event, the heavier spleens observed in the hypothermic group suggest that there may be considerable blood pooling in this organ during hypothermia. When this is considered with the finding of hemoconcentration during hypothermia which is abolished by splenectomy, the entire set of observations suggest a series of events involving splenic contraction early during hypothermia followed by subsequent pooling of blood, and particularly plasma, in this organ. Whether these considerations are correct must be established by further experimentation. Furthermore, it still remains to be established that a similar mechanism may be operative in man since, under normothermic conditions at least, splenic contraction is not considered to be an important mechanism in the regulation of circulatory blood volume in man, while it is a recognized mechanism in the dog. Therefore, in this particular case, involving the functional role of the spleen, species differences between man and dog may be particularly significant.

C. Artificial pacing

A series of animals were prepared by attaching electrodes on the right or left atrium and/or the right or left ventricle which were subsequently used to produce artificial pacing at a fixed rate. Generally the animals were first cooled and stabilized at 26 ± 1°C, their spontaneous rate was determined and atrial or ventricular pacing was instituted at the heart rate prevailing at that temperature. Subsequently the animals were maintained at this temperature for various periods of observation.

Rectangular pulses of 2 to 20 millisecond duration delivered from a Grass S4 electronic stimulator were used for pacing. Bipolar concentric electrodes were used to limit the current spread. The stimulating current was monitored as a voltage drop across a 100 ohm resistance on a dual beam oscilloscope. Further details of the methodology have been described previously (8,9,10).

1) Atrial pacing. Seven animals were paced, in the above described manner, from atrial electrodes. Two of these developed ventricular fibrillation soon after the institution of pacing. Three others became unresponsive to stimulation even with pulses of 10-30 millisecond duration with currents up to 10 milliamps within 3-4 hours after the onset of pacing (approximately 4-5 hours at 26 ± 1°C). The remaining two were successfully maintained at the pacing rate for more than 8 hours and were terminated. These results are summarized in Table 5.

Table 5. Mortality during atrial and/or ventricular pacing of dogs maintained at 26 ± 1°C.

	Number of animals	
	Atrial pacing	Ventricular pacing
Total tested	7	8
VF in 0 to 20 min	2	3
Dead in less than 5 hrs	3*	4
Survived 8 hrs or more	2	0

(*) Two in VF during subsequent ventricular pacing.

Two of the animals which became unresponsive to atrial stimulation were found to respond to ventricular stimulation and pacing but both developed ventricular fibrillation soon thereafter.

In successfully paced animals blood pressure was maintained at relatively high levels (above 90 mmHg) for the entire period of observation.

From these preliminary experiments, it was concluded that atrial pacing did not provide a satisfactory method for maintaining the heart rate during prolonged hypothermia. It was originally thought that this approach would provide information on the progressive bradycardia which develops spontaneously during prolonged hypothermia and its role in overall survival. However the development of ventricular fibrillation in a high proportion of animals soon after the onset of pacing, and presumably related to it, would tend to select the population and provide a very biased sample if only those animals which

do not fibrillate were to be studied. The same applies to the animals which could not be maintained on atrial pacing. For these reasons this approach was abandoned.

2) Ventricular pacing. Eight animals were studied with ventricular pacing using the same general methods as outlined above for atrial pacing. In this case it was generally possible to maintain pacing. However a marked hypotension developed as soon as ventricular pacing was instituted at the same heart rate as the prevailing sinus rate before the onset of pacing. The hypotension averaged 20-40 mmHg and was initially fully reversible by stopping ventricular pacing and allowing the return of the normal sinus rhythm.

This phenomenon has been previously observed in this and other laboratories and is apparently related to a depression of ventricular dynamics and possibly to effective closure of the A-V valves when excitation does not proceed from atria to ventricles and normal A-V delay is abolished. Previous studies made in this laboratory indicate that such hypotension due to ventricular pacing is exaggerated by cooling; this may be related to the slower ventricular excitation and onset of contraction in the hypothermic ventricle.

In any event, the hypotension produced by ventricular pacing, when added to the low blood pressure levels prevailing during hypothermic conditions produced shock-like levels of blood pressure (30-50 mmHg) which led to a rapid cardiovascular deterioration of the animal. Only one out of the eight animals survived more than five hours. Three of the animals terminated in ventricular fibrillation 10 to 30 minutes after the onset of ventricular pacing, the remaining terminated in profound hypotensive shock. These results are incorporated in Table 5.

On the basis of these preliminary results it was concluded that ventricular pacing, like atrial pacing but for different reasons, was not a suitable approach to the study of the effect of bradycardia on survival under prolonged hypothermia.

D. Catecholamine levels in tissues and blood

The status of the adrenergic system was studied by making measurements of catecholamines in selected tissues and in the circulation. In all cases determinations of norepinephrine (NE) and epinephrine (E) were made using the fluorometric method of von Euler and Lishajko (14). Details of the method as used in our laboratory have been published previously (11-13).

Briefly, the tissues were removed from the animal, blotted dry, weighed, and minced in cold trichloroacetic acid (3 mg/gm of tissue); the homogenates were filtered, adjusted to pH 8.3 and the catecholamines were adsorbed on specially prepared alumina columns; elution was performed with 0.5N acetic acid. Subsequently the amines were oxidized with FeSCN as the oxidant and the fluorescent derivatives were formed and stabilized with an alkali-ascorbic acid-ethylenediamine mixture as described by von Euler and Lishajko (14). Fluorescence measurements were made on a Turner fluorometer using the 405/495 and 436/525 pairs of excitation/fluorescence filters. The sensitivity of the method for tissues is of the order of 0.002 μg/gm. However all of the values are rounded to the nearest 0.01 μg/gm for tabulation, as finer precision appears to have no biological significance. Determination of plasma catecholamines with this method met with a number of difficulties which are discussed in the next section (D2).

1) Tissue catecholamines. Five dogs were cooled to 25°C and were subsequently sacrificed. The aorta, kidney, spleen and heart (left ventricle) of each animal were removed and analyzed for NE and E as outlined above. A similar group of control normothermic animals was kept under anesthesia for a similar period of time and sacrificed in the same manner. In both cases, the heart was removed while still beating, following thoracotomy under artificial respiration. The aorta, spleen, kidneys were then removed in that order as rapidly as possible. In no case was the time between death and placing the organ in trichloroacetic acid (including weighing procedure) more than 20 minutes, and usually it was of the order of 10 to 15 minutes.

Results of the determinations of NE for both sets of animals are shown in Table 6. In all cases the concentrations of E were very small, amounting to less than 5-10% of NE and no significant differences were observed between normothermic and hypothermic animals.

Table 6. Tissue catecholamine levels in normothermic and hypothermic dogs.

Normothermic Dog	Norepinephrine µg/gm Aorta	Kidney	Spleen	Heart*
#1	--	0.36	0.47	0.41
#2	0.40	--	0.39	0.39
#3	0.35	0.26	0.53	0.46
#4	0.34	0.54	0.57	0.53
#5	0.33	0.36	0.36	0.37
Mean NE µg/gm	0.36	0.38	0.46	0.43
Mean organ wt. (gm)	1.59	30.2	35.4	52.8
Hypothermic Dog				
#1	0.34	0.45	0.21	0.25
#2	0.31	0.30	0.24	0.17
#3	0.57	0.32	0.33	0.20
#4	0.33	0.56	0.38	0.13
#5	0.31	0.48	0.27	0.11
Mean NE µg/gm	0.37	0.42	0.29	0.17
Mean organ wt. (gm)	1.32	31.1	49.2	60.9

*Left ventricle.

The tabulated results on NE show that there is no significant difference in the levels present in the aorta or kidney between normothermic and hypothermic animals. However, the spleen and heart do show significant changes. In the case of the spleen, the difference may not be meaningful since the average weight of this organ was larger in hypothermic than in

normothermic animals. This suggests that a greater amount of blood was retained in the spleens of the hypothermic group which may be related to cardiovascular alterations occurring under hypothermia, producing a greater pooling of blood in this organ (also see Section B). In any event, when the total NE amount for the entire organ is considered there is no significant difference between normothermic and hypothermic animals; the average amounts of NE per spleen were 16.3 and 14.3 μg for the normothermic and hypothermic dogs respectively.

Most striking was the change in the NE content of the left ventricle. In this case, although there was a small difference in the mean organ weights between the normothermic and hypothermic group (Table 6), the difference is statistically significant ($P < 0.05$) whether the NE concentrations are considered as μg/gm or as the total amount of NE in the entire left ventricle. The average total NE was 22.7 and 10.4 μg for the normothermic and hypothermic ventricles respectively. Thus on either basis the hypothermic hearts contain about 40 to 45% the amount of NE present in the normothermic organ.

Actually the amount of NE found in the normothermic group was somewhat lower than that observed in previous studies made in this laboratory, where the heart was removed from animals which were maintained in the anesthetized state only for a short period of time (13). In those studies the mean NE (± standard deviation) for the left ventricle was found to be 0.56 ± 0.12. Thus it appears that maintaining normothermic animals in the anesthetized state for several hours does produce a decrease in the cardiac NE levels. However the effect of hypothermia is much more striking.

2) Blood catecholamines. Preliminary experiments were first made by removing blood using heparin as anticoagulant, centrifuging in a refrigerated centrifuge at 4°C to separate the plasma, and then assaying the plasma catecholamines with the fluorometric method of von Euler and Lishajko (14). This procedure gave poor recoveries and extremely variable results. This was true whether the plasma was passed through alumina without protein precipitation as suggested by von Euler (15) or when trichloroacetic acid (TCA) was used for protein precipitation following the same procedures as used for tissues.

To eliminate possible loss of catecholamines during the period of centrifugation, whole blood was employed in another series of analyses which was treated in a manner identical to that used for tissues; i.e. 1-2 ml of TCA per ml of blood was added immediately after withdrawal and the catecholamines were determined according to the method of von Euler and Lishajko (14). Previous preliminary experiments indicated that the red blood cells contained no catecholamines, which is in agreement with what is generally accepted (16).

The procedure using whole blood gave quite reproducible results but the calculated amounts of catecholamines per liter of blood were of the order of 10 to 20 μg/l, about 10 times higher than values reported for plasma catecholamine levels in other species, including man (16,17). However, Lund (18) has reported similarly high values for plasma catecholamines in the dog. At present it is not clear whether the high values obtained were due to the method employed providing little or no loss of amines after withdrawal and hence relating to a species difference, or, are due to the presence of some interfering substance in the dog blood. It is noteworthy however that with the same whole blood method on human blood samples, the values obtained in our laboratory were of the order of less than 0.05 to 0.8 μg/l of plasma, which agree well with values reported by others for human plasma (16,17). This favors the view that the high catecholamine values observed in the dog are due to species differences or to experimental conditions of anesthesia, etc., and are not a result of limitations in methodology. Nevertheless until this problem is resolved, extrapolation of the results to μg/l is not warranted. However, the relative values and the changes observed during experimental manipulations can still be considered. For this reason the values presented in Tables 7 through 10 are the actual fluorescence units observed (sample minus blood blank) from a sample of 20 ml of blood. The equivalent of 4 ml of blood were oxidized and 0.1 μg of NE standard gave 25 fluorescent units on the same scale. Thus the values tabulated correspond to μg/l of NE, although as noted above, this extrapolation may be of limited value.

Ten dogs were acutely cooled to 25°C. The changes in blood catecholamines as reflected by fluorescence units are shown in Tables 7 and 8.

Table 7. Blood catecholamine levels (fluorescence units) in five dogs cooled to 17°C.

	Temperature °C				
Dog	38	33	25	20	17
#1	12	23	8	6	3
#2	11	18	7	7	4
#3	10	17	7	6	4
#4	10	19	10	7	--
#5	24	30	18	7	8
Mean	13.4	21.4	10.0	6.6	6.3
% of Control	100	160	74	49	47

Table 8. Blood catecholamine levels (fluorescence units) in five dogs cooled to 25°C and maintained at that temperature.

	Temperature °C			Hours at 25°C		
Dog	38	33	25	1	2	3
#1	13	22	7	13	--	--
#2	12	23	8	15	26	32
#3	11	20	7	14	19	24
#4	11	19	7	13	--	--
#5	--	17	8	14	18	22
Mean	11.5	20.2	7.4	13.8	21.0	26.0
% of control	100	176	64	120	183	226
% of initial value at 25°C	--	--	100	186	284	351

It is clear from the results that at 33°C there is a definite increase in blood catecholamines amounting to about 165% of the control levels; at 25°C the blood catecholamines drop to about 65% of control.

Five of these dogs were cooled further to 20°C and this apparently produced a further drop in blood catecholamines. A greater decrease was observed in 3 out of 4 dogs which survived to 17°C (Table 7). The remaining five were maintained at 25°C for periods of one to three hours. During this period a striking increase in catecholamines was observed so that at three hours the levels were about twice the control values and three to four times the levels originally reached with cooling to 25°C (Table 8). Limitations in time and resources did not permit extending these observations to more prolonged periods of hypothermia.

It is noteworthy that all of the observed changes were very consistent (Tables 7 and 8). All dogs for which data are available showed an increase in catecholamines when the body temperature was lowered from 38°C to 33°C. Again all 10 dogs showed a decrease in catecholamine levels between 33°C and 25°C. Similarly, all 5 dogs showed an increase in catecholamine levels when maintained at 25°C for one hour. Thus all these observations are statistically significant, as the probability for such an occurrence by chance is extremely small and virtually negligible.

As controls, four dogs were maintained at normothermic temperatures for periods of four to five hours and blood samples were drawn for analysis hourly. The results are shown in Table 9.

Table 9. Blood catecholamine levels (fluorescence units) in four dogs maintained at normothermic temperatures (38°C) for a period of five hours.

	Hours at 38°C					
Dog	0	1	2	3	4	5
#1	10	8	15	8	7	14
#2	15	15	7	8	12	6
#3	10	8	3	6	4	-
#4	8	6	6	6	6	5
Mean	10.8	9.3	7.8	7.0	7.3	8.3
% of initial	100	86	72	65	68	77

Variations in the blood catecholamine levels observed in these animals might be related to the degree of anesthesia which is difficult to maintain exactly at the same level over such periods in normothermic animals. Nevertheless the results show that over this period there was an average decrease ranging from 85 to 65% of initial values. Thus the changes observed under hypothermia (Tables 7 and 8) must be attributed to the effects of cold rather than to any non-specific effect associated with the period of observation.

In two animals functional adrenalectomy was performed by ligating the renal pedicles, including the adrenal arteries and veins, prior to cooling. One of these was cooled to 17°C, the other was cooled to and maintained at 25°C. The data are presented in Table 10.

Table 10. Blood catecholamine levels (fluorescence units) in two dogs cooled after ligation of the adrenal vessels.

Dog	38°C	33°C	25°C			20°C	17°C
			0 hr	1 hr	2 hrs		
#1	6	10	13	15	18	--	--
#2	6	9	10	--	--	8	3

It is clear that these preliminary experiments give no indication that functional adrenalectomy alters the blood catecholamine responses of the animal, since the results shown in Table 10 exhibit the same pattern as those from other hypothermic animals shown in Tables 7 and 8.

V CONCLUSIONS

A number of factors were examined in order to establish their connection with the cardiovascular collapse leading to death during prolonged hypothermia. Previous observations that roughly 50% of the animals die when maintained at 25°C for a period of 16 to 18 hours were confirmed. In addition it was shown that less than 10% mortality occurs in anesthetized control animals maintained at normothermic temperatures over

a similar period of time. As in the previous study, hemoconcentration was observed during cooling to 25°C with a further increase in hematocrit when the animals were maintained at this hypothermic temperature for several hours. By contrast normothermic controls showed only small changes in hematocrit over the same period. In preliminary experiments the changes in hematocrit occurring in hypothermia were found to be abolished by functional splenectomy. However the spleens of hypothermic animals were actually heavier than those of the normothermic controls.

Artificial atrial and/or ventricular pacing with electronic pacemakers was examined as possible means of limiting the effects of the progressive bradycardia previously observed during prolonged hypothermia. This technique was not found to be useful due to the frequent development of ventricular fibrillation and other limitations of the cardiac dynamics under hypothermia.

The status of the adrenergic system was examined by determining tissue and blood catecholamine levels. Hypothermia had no significant effect on the catecholamine levels of the aorta or of highly vascular adrenergically innervated organs such as the spleen or kidney; however it reduced the cardiac norepinephrine levels to less than 50% of the corresponding control values. Blood catecholamines consistently rose while cooling from 38°C to 33°C where they reached a maximum and decreased below control levels as cooling advanced to temperatures of 25°C or lower. However when hypothermia was maintained at 25°C, blood catecholamines rose to reach control pre-cooling levels by one hour and reached two to three times the control levels after three hours.

These observations are taken to suggest that there are drastic alterations in the adrenergic mechanisms during hypothermia during both the acute phase and prolonged maintenance of the hypothermic state. Such alterations may be expected to produce significant changes in cardiovascular functions and may play a key role in the factors which limit survival during prolonged hypothermia. An extensive investigation of the adrenergic mechanisms especially those involved in the control of cardiovascular functions is needed.

REFERENCES

1. Angelakos, E.T. Studies at moderate hypothermic temperatures of factors affecting survival under prolonged hypothermia. AMRL-TDR-62-130. 6570th Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, Nov 1962. AD 297 348.

2. Spurr, G.B., B.K. Hutt and S.M. Horvath. "Prolonged hypothermia in the dog." Am. J. Physiol. 178:275-282, 1954.

3. Popovic, V. "De l'hypothermie léthargique prolongee." Arch. des Sci. Physiol. 9:219-229, 1955.

4. Popovic, V. "Physiological characteristics of rats and ground squirrels during prolonged lethargic hypothermia." Am. J. Physiol. 199:467-471, 1960.

5. Connaughton, P.J. and F.J. Lewis. "Hypothermia below 25°C for one day in the rat." J. Appl. Physiol. 17:107-109, 1962.

6. Connaughton, P.H., G. Holt and F.J. Lewis. "Prolonged hypothermia for periods over 20 hours: influence of therapy and technique on survival." Surgery 50:372-381, 1961.

7. Hock, R.J. "The potential application of hibernation to space travel." Aerospace Med. 31:485-489, 1960.

8. Angelakos, E.T., E.G. Laforet and A.H. Hegnauer. "Ventricular excitability and refractoriness in the hypothermic dog." Am. J. Physiol. 189:591-595, 1957.

9. Hegnauer, A.H. and E.T. Angelakos. "Excitable properties of the hypothermic heart." Ann. N.Y. Acad. Sci. 80:336-347, 1959.

10. Torres, J.C., E.T. Angelakos and A.H. Hegnauer. "Strength-duration curves in the hypothermic dog heart." Am. J. Physiol. 196: 1005-1007, 1959.

11. Angelakos, E.T. and M.L. Torchiana. "Positive inotropic responses and catecholamine content of isolated rabbit atria exposed to tyramine." Acta physiol. scand. 59:161-168, 1963.

12. Angelakos, E.T., K. Fuxe and M.L. Torchiana. "Chemical and histochemical evaluation of the distribution of catecholamines in the rabbit and guinea pig hearts." Acta physiol. scand. 59:184-192, 1963.

13. Angelakos, E.T. "Regional distribution of catecholamines in the dog heart." Circulation Res. 16:39-44, 1965.

14. Euler, U.S.v. and F. Lishajko. "Improved technique for the fluorimetric estimation of catecholamines." Acta physiol. scand. 51:348-355, 1961.

15. Euler, U.S.v. (Personal communication.)

16. Euler, U.S.v. Noradrenaline. Springfield, Ill., C. Thomas Publ., 1956.

17. Udenfriend, S. Fluorescence Assay. New York, Academic Press, 1962.

18. Lund, A. Adrenaline and Noradrenaline. Köpenhamn, Munksgaard, 1951.

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*
Boston University School of Medicine
Department of Physiology
Boston, Massachusetts

2a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

2b. GROUP
N/A

3. REPORT TITLE

FACTORS AFFECTING SURVIVAL DURING PROLONGED HYPOTHERMIA

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
Final report, February 1963 - April 1965

5. AUTHOR(S) *(Last name, first name, initial)*
Angelakos, E. T., MD, PhD

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
December 1965	20	18

8a. CONTRACT OR GRANT NO. AF 33(657)-10755
b. PROJECT NO. 7222 and 7164
c. Task Nos. 722204 and 716409
d.

9a. ORIGINATOR'S REPORT NUMBER(S)

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
AMRL-TR-65-182

10. AVAILABILITY/LIMITATION NOTICES
Distribution of this document is unlimited.

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY
Aerospace Medical Research Laboratories, Aerospace Medical Div., Air Force Systems Command, Wright-Patterson AFB, Ohio

13. ABSTRACT

The mortality of anesthetized dogs maintained under prolonged hypothermia was studied and the factors responsible for death were evaluated. In the technically acceptable experiments, 45% of the dogs maintained at moderate hypothermic temperatures (26° ±1°C) died within 16 hours. The corresponding mortality in normothermic (38°C) control dogs was 7%. Progressive hemoconcentration and bradycardia were observed during prolonged hypothermia. The former could be abolished by splenectomy. The use of artificial pacemakers to limit the effects of bradycardia was unsuccessful due to the development of other cardiovascular complications. Blood catecholamine levels increased with cooling to 33°C but decreased below control levels at or below 25°C; however, prolonged hypothermia at 25°C was associated with a progressive increase in blood catecholamines up to two to three times the initial control levels. The catecholamine content of aorta, kidney and spleen was not altered significantly by hypothermia, however, cardiac catecholamines decreased to below 50% of control with cooling to 25°C. Adrenergic mechanisms apparently play a key role in the alterations of cardiovascular functions which limit survival during prolonged hypothermia.

DD FORM 1 JAN 64 1473

Security Classification

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Hypothermia						
Laboratory animals						
Exposure						
Heart						
Spleen						
Kidneys						
Aorta						
Medical Research						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through _____."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through _____."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through _____."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS), (S), (C), or (U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.

Security Classification

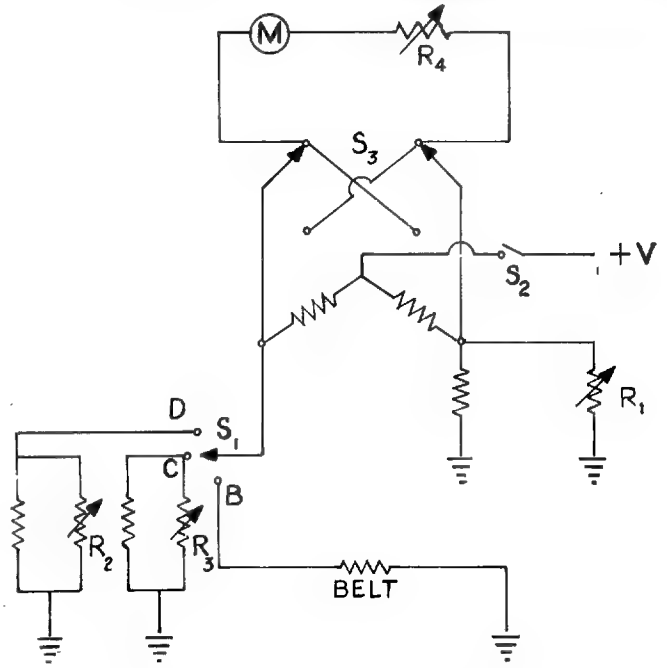


Fig. 2. Temperature Sensor Bridge Circuit.

allow the subject free and easy access to all areas within the experimental chamber.

The Temperature Sensor—The temperature sensor is a length of No. 44 Balco wire (70 per cent nickel, 30 per cent iron) sealed between two layers of teflon-backed pressure sensitive tape. The total resistance of the sensor is about 750 ohms at room temperature, and the temperature coefficient is approximately 2 ohms per degree Fahrenheit. The bridge and calibration circuit used is shown in Figure 2. The experimenter obtains periodic sensor readings by placing switch S_1 in position B and then closing switch S_2 which connects the circuit to a standard 22.5 volt battery. A reading is then available at M, a sensitive microammeter. Switch S_2 is closed *only* when making readings or calibrations.

The bridge circuit is calibrated with the sensor to be used for a meter sensitivity of 0.5 microampere per degree Fahrenheit. The meter used in the present study enabled temperature measurements to the nearest 1/10th of one degree Fahrenheit. The calibration procedure is as follows: (1) The sensor (belt) is immersed in a water bath of 98.6° Fahrenheit. Variable resistor R_4 is set to zero resistance for maximum meter sensitivity, and switch S_1 is set to position B. Resistor R_1 is then adjusted to obtain a null reading on the microammeter, M. Following this adjustment, switch S_1 is moved to position D, and resistor R_2 is adjusted to obtain a null reading on the microammeter, M. (2) The sensor is now immersed in a water bath of 99.6° Fahrenheit, and switch S_1 is again set to position B. Variable resistor R_4 is now adjusted so that the meter reads plus 0.5 microampere when the polarity reversing switch, S_3, is in the appropriately labeled direction for positive current readings. Following this adjustment, switch S_1 is moved to position C, and resistor R_3 is adjusted to obtain the same plus 0.5 microampere reading as previously obtained with the switch S_1 set to the B position.

Once this calibration procedure is completed, the bridge can thereafter be internally calibrated for use with this particular sensor (belt) without recourse to water baths. Internal calibration is accomplished by checking the balance and imbalance conditions with switch S_1 set at D and C respectively and making any necessary sensitivity adjustments on resistor R_4 during the imbalance check. The complete external calibration procedure must be repeated if a different temperature sensor is used.

The Experiment—The feasibility of using this harness-mounted skin temperature sensor for long term monitoring purposes was examined in a study involving the behavioral and physiological testing of subjects for a 48-hour period. Subjects in this experiment were individually isolated in an experimental chamber for a 48-hour period in which they were exposed to one of the four following work-rest schedules: *Schedule 1*, alternating work and rest periods, each period one-half hour in length; *Schedule 2*, alternating work and rest periods, each period one hour in length; *Schedule 3*, alternating work and rest periods, each period one and one-half hours in length; *Schedule 4*, alternating work and rest periods, each period two hours in length. Details of the basic experimental design and the variables measured are described in an earlier report.[13] Only the heart-rate and body temperature data are reported in this paper.

Body temperature and heart-rate readings were taken once every ten minutes during all rest periods for all four work-rest schedules. Since the basic experimental design resulted in all subjects, regardless of schedule, having a total of 24 hours of rest time in the course of the 48-hour experimental sessions, 144 matching heart-rate and skin temperature measurements were scheduled for each of the subjects tested.

Subjects—Twenty-three subjects were each administered one of the four work-rest schedules. The subjects were all at least 21 years of age and in apparent good health. The mean age of the subjects was 23.1 years. Subjects were informed that the experiment would last 48 hours. During the course of the experiment, subjects were not allowed any information concerning the passage of time, and specific details as to the nature of the work-rest schedule administered were not given to the subjects. Experimental schedules were assigned to the subjects randomly using a double blind technique to prevent either the experimenters or the subjects from knowing the experimental conditions assigned prior to the actual onset of the sessions. Twenty-one of the subjects completed the full 48-hour session. One subject terminated the experiment for personal reasons, and one session was terminated by the experimenters due to a major equipment failure. All subjects wore the harness system for the entire period of confinement.

RESULTS

The harness system proved to be reasonably comfortable for the subjects. The adjustable features of the

"Wet" Versus "Dry" Suit Approaches to Water Immersion Protective Clothing

R. F. Goldman, Ph.D., J. R. Breckenridge, B.S.,
Commander E. Reeves, MSC, USN, and Captain E. L. Beckman, MC, USN

Immersion protection flight clothing can be of either a skin diver, "wet" suit type or waterproof, "dry" suit. A waterproofed copper manikin was used to study the insulative properties of both types of suits, in air and also during water immersion. The bulkier characteristics of the dry suit studied, the Mark 5A, provided greater insulation in air than either a 1/4" or 3/16" unicellar sponge, neoprene wet suit. However, during water immersion, compression of the "dry" suit by the water reduced the insulation by 75 per cent. The insulation of the "wet" suits was also reduced but these suits are less compressible and thus during water immersion provide significantly more insulation than the "dry" suit.

EMERGENCIES DURING FLIGIITS over water frequently have as a sequitur, immersion of pilot and/or crew in water for periods of one to many hours before rescue.[11] With special protective clothing, tolerances in 5°C water, of up to 3 hours have been reported.[2] However, without such clothing, submersion to the shoulders in water of 2 to 12°C can be fatal in 53 to 105 minutes.[1,12] While such biological factors as physical condition,[3] amount of body fat[4,10] and level of activity maintained[5] are all involved in the resistance to heat loss during water immersion, the high thermal diffusivity of water, compared to that of air, damps the difference in cooling associated with biological factors.[10] The only practical solution will be found in providing insulation to reduce this heat loss. Hall, *et al.*, in a series of articles between 1954 and 1958[6,7,8] explored relative heat loss in wet and dry clothing. They concluded that utilization of a "wet" suit, a suit of unicellular foam rubber which does not prevent water entry but restricts free flow over the body surface, offered some practical advantages, confirming earlier Navy studies.[18] Improvements in "wet" suits have continued, and will lead ultimately to an auxiliary heated "wet" suit[8]; developments in waterproof fabrics and closures have also taken place, leading to the development of waterproof "dry" immersion suits. This paper presents the results of a study in which a heated copper manikin was used to measure the insulation provided by three immersion protection ensembles, one a "dry" suit and two "wet" suits of differing thickness, in air and during immersion in water.

From the U. S. Army Research Institute of Environmental Medicine, Natick, Massachusetts, and the U. S. Naval Medical Research Institute, Bethesda, Maryland.

The opinions or assertions expressed herein are the private ones of the authors and are not to be construed as official or reflecting the views of the Navy Department or the Naval Service at large.

MATERIALS AND METHODS

Thermal insulating values of three Navy immersion suits were determined on an electrically-heated Copper Man in air, and with the manikin immersed to the neck in still and moving water. Measurements were also taken with the manikin nude to estimate the insulation provided by the air or water films at the surface of the clothing.

The three suits as used on the manikin were as follows:

a. Mark 5A waterproof immersion suit consisting of Mark 5A air-ventilated liner and Mark 5A outer coverall. The gloves normally worn with this suit could not be fitted on the manikin. In their place, a pair of standard Army cold-wet mitten inserts, covered for the water runs with thin plastic glove covers, were used to provide an equivalent (by estimate) insulation. A second change, use of more heavily insulated boots (boot, insulated, Arctic, white) than normally worn with this suit, was dictated by the need for size 13R boots on this manikin. No headgear was used with this system or with the two wet suits described below.

b. Underwater swimmer's wet suit, consisting of jacket, trousers, and booties of ¼" unicellular sponge neoprene. The neoprene hood and gloves of this ensemble were not used; woolen mittens and plastic shells were used for handwear as with suit a.

c. Helicopter crew immersion suit, wet suit type, experimental, consisting of jacket, trousers and booties of 3/16" nylon coated unicellular foamed neoprene. Other dressing details were the same as for suit b.

The manikin used was a life-sized, erect, copper shell waterproofed by brushing on several coats of reclaimed rubber undercoating compound. The shoulder, wrist and foot joints were strengthened and immobilized by wrapping with a layer of nylon netting between coats. This manikin is heated by a single circuit of resistance wire cemented to the inside. Ten thermistor sensors (wired in series) and 19 thermocouples in the shell are used for controlling and measuring its temperature. The couples are evenly spaced over the surface, allowing use of a simple arithmetic average in calculating the average surface temperature. Cables to the manikin are brought out through the eyes and connect to a central unit which includes an electronic on-off temperature controller, a voltage stabilizer, and

meters and timers for determining the average power input to the manikin. Connections to a 20-point temperature recorder are also brought out of the unit.

For insulation studies in air, the manikin was placed in the center of a constant temperature room maintained at 80°F ±1°F and 50 per cent relative humidity, with air movement approximately 50 ft/min. Average surface temperature was maintained constant within 1°F at approximately 95°F. After equilibration (2 to 3 hours), two half-hour records were made of manikin surface temperatures, air temperature (recorded from a single thermocouple near the manikin) and power input data. The latter consisted of voltage and amperage readings, relay "on" time, and total observation time. Surface temperatures were recorded at various times in the heating and cooling cycles to insure a representative average. Thermal insulation, in clo units, for the suits plus boundary air layer was calculated from the equation:

$$\text{clo} = \frac{3.09\ (T_s - T_a)\ (A)}{.86\ (E)\ (I)\ (F)}$$

where T_s = average surface temperature, °F
T_a = air temperature, °F
A = manikin surface area, 1.86 m²
E = manikin supply voltage, A.C. volts (RMS)
I = current, amperes
F = relay "on" time divided by total time

The tank used for the water immersion studies was 3 feet in diameter and 6 feet in height with a valved inlet near the bottom and an outlet pipe 5 feet up the wall. This pipe was fitted with a 90° elbow, an 8" nipple, a second elbow, and a tee for venting the outlet line (anti-siphon device). Turning this array adjusted the height of the second elbow and with it the water level in the tank (above the outlet pipe).

For the still water runs, the tank was simply filled to the desired level. In most of the other runs a slow water circulation was provided by connecting the tank to an external 15-gallon water bath equipped with a pump which delivered up to 2 gal/min to the tank. This flow rate was usually reduced to about 1 gal/min to avoid overloading the overflow and return line (which would cause poor level control). Increased circulation was provided in one run by stirring the water and in another by introducing compressed air at the bottom. This caused violet agitation and mixing, especially near the surface.

Procedures used in determining insulations of the three suits in water were the same as in air. Manikin surface temperature was controlled within ±1°F at about 95°F and water temperature remained practically constant at 80°F. The tank was located in the constant temperature room set as in the air exposures and no other control on water temperature was necessary. It was measured with a thermocouple in a thin plastic sheath, and checked for accuracy with a thermistor thermometer and a mercury thermometer. The manikin, which weighs only 75 pounds but displaces a volume of water equivalent to that of a man, was held down by clamping the ankles to its support stand, weighting the base, and lowering a ring normally used around the head until it rested on the shoulders; all surfaces in contact with the manikin were wood or nonconductive sponge. Manikin and tank were electrically grounded to protect personnel in the event water leaked through the surface coating.

RESULTS

Insulating values in air and water are given in clo units for the manikin nude and dressed in each of the three ensembles (Table I). Values include the insulation of the boundary air or water film at the surface of the clothing; these film insulations for the clothed manikin are approximately equal to the value for the nude manikin, i.e., 0.62 clo in air and 0.14 clo in still water. The values in circulating water are separated according to the technique used, i.e., flow or stirred.

TABLE I. TOTAL INSULATING VALUES IN AIR AND WATER
(clo units)

Suit	Air	Still Water	Water Flow lgpm	Stirred Water
Nude Manikin	0.62	0.14	—	0.11
Mark 5A Immersion Dry Suit	2.05	0.56	0.57	—
Underwater Swimmers Wet Suit (¼" Neoprene)	1.48	0.76	0.77	0.71
Helicopter Crew Wet Suit (3/16" Neoprene)	1.32	—	0.78	—

DISCUSSION

The Mark 5A suit is a loosely-fitting two-layer ensemble which derives much of its insulation from air trapped between layers. In air, the Mark 5A suit provides more insulation than the ¼" and 3/16" wet suits (0.5 and 0.7 clo higher respectively). In water, however, the two wet suits provide 0.2 clo more insulation than the Mark 5A, as its layers collapse inward against the manikin, the air spaces disappear, and thus the Mark 5A insulation falls off sharply. On the other hand, the wet suits are designed to fit snugly and use a relatively thick layer (compared with those in the Mark 5A suit) to provide insulation. The results indicate that the sponge neoprene used in these suits is compressed only slightly under water. Hall has previously noted the relationship between improved protection and greater resistance to compression.[7]

An estimate of 1/15th of an inch on the average for the compression of the ¼" suit system could be made using the 3 clo/inch relation for foamed neoprene,[2] since the intrinsic insulation of the ¼" thick wet suit (total value less that for the nude manikin) was only 0.2 clo less in still water than in air (0.62 clo vs 0.86 clo). However, laboratory studies on ⅛" neoprene foam have indicated that the compression at the pressure equivalent to this water level, estimated as 2½ feet on average, would only be some 2/1000 of an inch[2]; while a ¼ inch suit should be more compressible, the disproportion appears too great. Substitution of water (.266

clo/inch) for only a 1/30″ thickness of trapped air next to the skin (6.13 clo/inch) is a more reasonable explanation. Reduction in the insulation of the 3/16″ thick wet suit was apparently even less than that of the ¼″ suit under water. The 3/16″ thick suit was easier to put on the manikin and perhaps provided a better fit, thus allowing less substitution of water for trapped air. This foam also may have been less dense than the ¼″ foam; since solid neoprene only provides 0.9 clo/inch; the less dense the composition of the suit, the better the insulation for an equivalent thickness.

From this study it appears that the boundary water film insulation is quite small and only slightly affected by the water velocity over the surface. The value for the nude manikin was 0.14 clo in still water which was reduced to 0.11 clo with violent agitation (stirring with a paddle, bubbling air through water or mechanical stirring produced the same value). A similar decrease with the ¼″ wet suit (0.76 to 0.71 clo) is evidence of a like effect on the film at the surface of the neoprene. Studies on this aspect of the problem are planned.

It would appear that the "dry" suit, which is bulkier in air and hence imposes more insulation on the wearer, also is compressed significantly more than a "wet" suit upon water immersion and then provides less protection than the wet suit. Maximum insulation in water but minimum in-flight insulation, and encumbrance, are desirable characteristics. The "wet" suit approach is certainly preferable in this regard. There are additional problems with maintaining the dry state of the "dry" suit. Closure leakage is a frequent problem, porous diffusion may occur, particularly in well worn suits, and emergency evacuation of an aircraft frequently is accompanied by superficial lacerations[11] which would ruin a "dry" suit while even more severe damage would do little to impair a "wet" suit. The well known physiologic phenomenon of cold diuresis would also be a problem in maintaining a "dry" suit, but could be ignored in a wet suit. For comfortable wear in flight, ventilation systems to prevent insensible sweat accumulation are required with either the impermeable "dry" or "wet" suit; provision of in-flight comfort is a ventilating system design problem common to both approaches. Since the only reason for wearing anti-immersion garments in flight is to provide protection in the event of water immersion, it would seem that the "wet" suit approach, which provides the better protection in such an eventuality, is preferable to the "dry" suit. In air, an average man (1.8m² body surface area) wearing the dry suit would lose, by radiation and convection, 8.8 kcal per hour of body heat for each °F difference between his average skin temperature and the ambient air temperature, whereas wearing the Helicopter crew, 3/16″ wet suit he would lose 13.6 kcal per hour per °F or 55 per cent more. Thus if overheating during in-flight wear is a problem, the wet suit advantage is obvious. Comparable figures during water immersion are 32.1 kcal per hour per °F difference between skin and water temperature in the dry suit, and 23.7 kcal with 3/16″ wet suit, representing a conservation of 26 per cent of the heat lost when wearing a dry, "dry suit." This conservation would be even greater if rips, closure leakage, cold diuresis or age induced porosity in the dry suit reduced its insulation value still further.

ACKNOWLEDGEMENTS

We wish to acknowledge the skill of Mr. Harold Hanson in waterproofing the manikin without drastically altering its surface heat transfer characteristics and to thank him for his assistance with these measurements.

REFERENCES

1. Alexander, A.: The Treatment of Shock from Prolonged Exposure to Cold, Especially in Water. Rpt 250, U. S. Dept. of Commerce, 1945.
2. Beckman, E. L.: Thermal Protection During Immersion in Cold Water. Second Symp. on Underwater Physiology. Publ. 1181 NAS-NRC, Washington, D. C., 1963, pp. 247-266.
3. Beckman, E. L., Reeves, E. and Goldman, R.: A Review of Current Concepts and Practices Applicable to the Control of Heat Loss During Water Immersion. *Aerospace Med.* 36:136-137, 1965.
4. Carlson, L. D., Hsieh, A. C. L., Fullington, F., and Elsner, R. W.: Immersion in Cold Water and Body Tissue Insulation. *J. Aviat. Med.* 29:145-152, 1958.
5. Glaser, E. M.: Immersion and Survival in Cold Water. *Nature* 166:1068, 1950.
6. Hall, J. F., Jr., Kearney, A. P., Polte, J. W., and Quillette, S.: Body Cooling in Wet and Dry Clothing. *J. Appl. Physiol.* 13:121-128, 1958.
7. Hall, J. F., Jr., and Polte, J. W.: Effect of Water Content and Compression on Clothing Insulation. *J. Appl. Physiol.* 8:539-545, 1956.
8. Hall, J. F., Jr., Polte, J. W., Kelley, R. L., and Edwards, J., Jr.: Skin and Extremity Cooling of Clothed Humans in Cold Water Immersion. *J. Appl. Physiol.* 7:188-195, 1954.
9. Keatinge, W. R.: The Effect of Work and Clothing on the Maintenance of the Body Temperature in Water. *Quart. J. Expt. Physiol.* 46:69-82, 1961.
10. Keatinge, W. R.: The Effects of Subcutaneous Fat and of Previous Exposure to Cold on the Body Temperature, Peripheral Blood Flow and Metabolic Rate of Men in Cold Water. *J. Physiol.* 153:166-178, 1960.
11. Llano, G. A.: *Airmen against the sea.* ADTIC Publ. G-104. Arctic Desert Tropic Information Center, Maxwell AFB, Alabama.
12. Molnar, G. W.: Survival of Hypothermia by Men Immersed in the Ocean. *J.A.M.A.* 131:1046-1050, 1946.
13. Bradner, H.: Co-operative Underwater Swimmers' Project. In: N.R.C. Comm. on Amphibious Operations Rpt. 0033. Jan. 1953, pp. 36-57.

Method of Recording Body Temperature for Prolonged Time

DONALD I. TEPAS, PH.D., and MICHAEL A. B. VIANELLO, B.A.

A harness-mounted temperature sensor was developed for prolonged monitoring of human skin temperature. This sensor was 30 inches by 1 inch in size and was mounted in an adjustable harness which held the sensor in close contact with the chest. Temperature measurements, together with concomitant heart rate readings, were recorded from subjects in the course of 48-hour experimental sessions. The harness proved to be a reasonably comfortable item for the subjects to wear. The temperature measures display many of the characteristics associated with standard body temperature recordings, and the heart rate changes obtained agree with the temperature changes recorded. The results suggest that this may be a promising technique for monitoring body temperature changes remotely in the course of extended space travel. Additional parametric research is needed to completely assess this approach.

BODY TEMPERATURE is a physical parameter measured by many biomedical monitoring systems. Rectal, oral, and skin surface sensors have been used. In general, the rectal probe provides the most reliable device for continuous monitoring purposes.[2] When long-term monitoring is contemplated, however, comfort must be considered, and thus a rectal probe is usually not used. For example, the Mercury Project monitoring system switched from a rectal probe to an oral probe for the longer duration MA-9 flight.[3] An oral sensor has many limitations which indicate that it is not the final solution to this aspect of the long term monitoring problem. Oral readings are influenced by eating and breathing activities. Readings also require assistance from the subject since continuous presence of the probe in the mouth is normally not desirable.

Skin surface temperature sensors have a number of limitations which have restricted their use: maintenance of good contact between the sensor and the skin is frequently difficult; positioning of the probe is quite critical; measurements are sometimes extremely sensitive to movement and environmental artifacts; and, relatively little is known about the relationship of skin temperatures to various medical parameters. The present study examines the feasibility of developing a skin temperature sensor which will overcome many of these limitations.

From the Human Factors Group, Research Department, Systems and Research Division, Honeywell, Inc., St. Paul, Minnesota.

This paper is based on research conducted at Honeywell under U.S. Air Force contract.

Presented at the Aerospace Medical Association Annual Meeting, New York, New York, 1965.

Russian reports indicate that a harness system for applying electrodes provides a comfortable and reliable method for obtaining electrocardiogram signals during prolonged space flight.[1] Adopting a similar approach, a harness-mounted skin temperature sensor was designed. The harness is part of a laboratory physiological monitoring system which has been described in a previous report.[14]

MATERIALS AND METHODS

The Harness—The harness developed is shown in Figure 1. This harness is worn as an undergarment, and it is equipped with elastic straps and adjustable insert panels which assure a snug but comfortable fit for a wide range of subjects. The system permits monitoring of the electroencephalogram (EEG), the electrocardiogram (ECG), and skin temperature. The temperature sensor is a 30 inch by 1 inch ribbon held in close contact with the subject's chest surface by the harness as indicated in Figure 1. This large-surface temperature sensor was developed in an attempt to increase the sensitivity of the measurements made and to minimize effects resulting from relatively small local changes in skin surface contact. For the present study, a direct-wire connection was made between the harness system and the required amplifier and/or bridge circuits used. This connection was made via a lightweight multiple conductor cable of sufficient length to

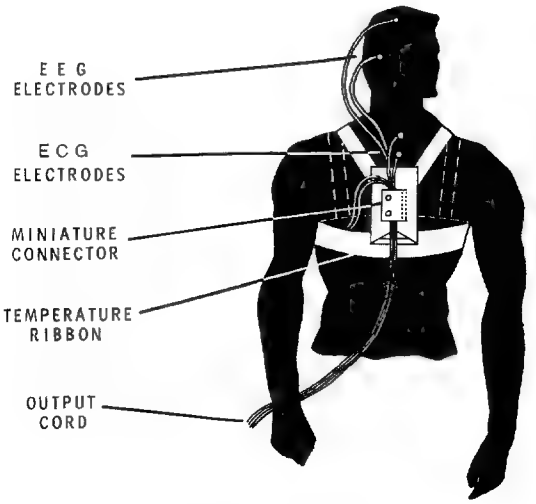


Fig. 1. The Harness System.

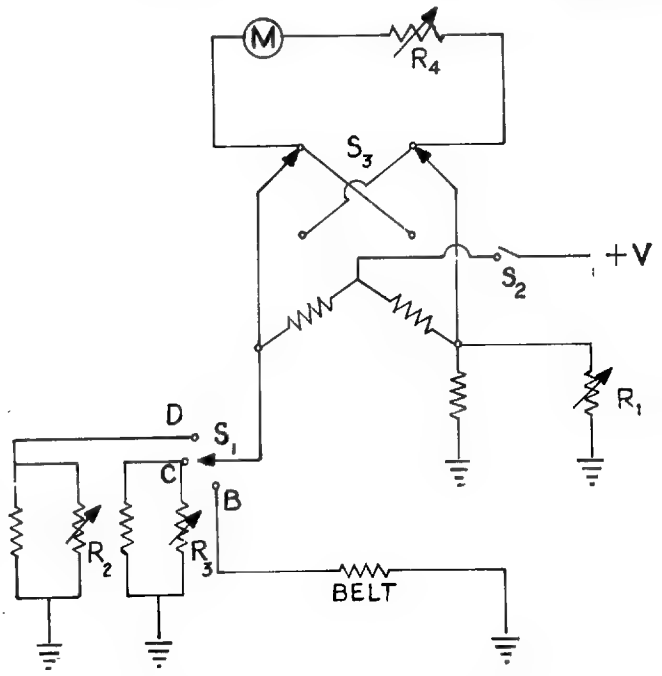


Fig. 2. Temperature Sensor Bridge Circuit.

allow the subject free and easy access to all areas within the experimental chamber.

The Temperature Sensor—The temperature sensor is a length of No. 44 Balco wire (70 per cent nickel, 30 per cent iron) sealed between two layers of teflon-backed pressure sensitive tape. The total resistance of the sensor is about 750 ohms at room temperature, and the temperature coefficient is approximately 2 ohms per degree Fahrenheit. The bridge and calibration circuit used is shown in Figure 2. The experimenter obtains periodic sensor readings by placing switch S_1 in position *B* and then closing switch S_2 which connects the circuit to a standard 22.5 volt battery. A reading is then available at *M*, a sensitive microammeter. Switch S_2 is closed *only* when making readings or calibrations.

The bridge circuit is calibrated with the sensor to be used for a meter sensitivity of 0.5 microampere per degree Fahrenheit. The meter used in the present study enabled temperature measurements to the nearest 1/10th of one degree Fahrenheit. The calibration procedure is as follows: (1) The sensor (belt) is immersed in a water bath of 98.6° Fahrenheit. Variable resistor R_4 is set to zero resistance for maximum meter sensitivity, and switch S_1 is set to position *B*. Resistor R_1 is then adjusted to obtain a null reading on the microammeter, *M*. Following this adjustment, switch S_1 is moved to position *D*, and resistor R_2 is adjusted to obtain a null reading on the microammeter, *M*. (2) The sensor is now immersed in a water bath of 99.6° Fahrenheit, and switch S_1 is again set to position *B*. Variable resistor R_4 is now adjusted so that the meter reads plus 0.5 microampere when the polarity reversing switch, S_3, is in the appropriately labeled direction for positive current readings. Following this adjustment, switch S_1 is moved to position *C*, and resistor R_3 is adjusted to obtain the same plus 0.5 microampere reading as previously obtained with the switch S_1 set to the *B* position.

Once this calibration procedure is completed, the bridge can thereafter be internally calibrated for use with this particular sensor (belt) without recourse to water baths. Internal calibration is accomplished by checking the balance and imbalance conditions with switch S_1 set at *D* and *C* respectively and making any necessary sensitivity adjustments on resistor R_4 during the imbalance check. The complete external calibration procedure must be repeated if a different temperature sensor is used.

The Experiment—The feasibility of using this harness-mounted skin temperature sensor for long term monitoring purposes was examined in a study involving the behavioral and physiological testing of subjects for a 48-hour period. Subjects in this experiment were individually isolated in an experimental chamber for a 48-hour period in which they were exposed to one of the four following work-rest schedules: *Schedule 1*, alternating work and rest periods, each period one-half hour in length; *Schedule* 2, alternating work and rest periods, each period one hour in length; *Schedule 3*, alternating work and rest periods, each period one and one-half hours in length; *Schedule 4*, alternating work and rest periods, each period two hours in length. Details of the basic experimental design and the variables measured are described in an earlier report.[13] Only the heart-rate and body temperature data are reported in this paper.

Body temperature and heart-rate readings were taken once every ten minutes during all rest periods for all four work-rest schedules. Since the basic experimental design resulted in all subjects, regardless of schedule, having a total of 24 hours of rest time in the course of the 48-hour experimental sessions, 144 matching heart-rate and skin temperature measurements were scheduled for each of the subjects tested.

Subjects—Twenty-three subjects were each administered one of the four work-rest schedules. The subjects were all at least 21 years of age and in apparent good health. The mean age of the subjects was 23.1 years. Subjects were informed that the experiment would last 48 hours. During the course of the experiment, subjects were not allowed any information concerning the passage of time, and specific details as to the nature of the work-rest schedule administered were not given to the subjects. Experimental schedules were assigned to the subjects randomly using a double blind technique to prevent either the experimenters or the subjects from knowing the experimental conditions assigned prior to the actual onset of the sessions. Twenty-one of the subjects completed the full 48-hour session. One subject terminated the experiment for personal reasons, and one session was terminated by the experimenters due to a major equipment failure. All subjects wore the harness system for the entire period of confinement.

RESULTS

The harness system proved to be reasonably comfortable for the subjects. The adjustable features of the

harness resulted in a tight fit for all subjects tested without any modification of the basic design. Subjects were able to work, rest, eat, and toilet with the harness on, and no significant restriction in activity was observed or reported. No medical complications of any sort were observed at termination. Of the 21 subjects completing the experiment, complete heart-rate data was obtained from 16 subjects and complete temperature data was obtained from 14 subjects. Partial data was obtained from the remaining subjects due to a variety of minor electronic malfunctions. Incomplete temperature data was the result of a broken temperature sensor in only three cases.

Skin temperature and heart-rate measures were grouped for analysis in two ways: *cycle* analysis—grouping all of the measures collected during any given rest period; and *period* analysis—grouping measures according to when they were collected within rest periods. Grouping data by *cycles* yielded information concerning long-term changes during the 48-hour period, such as circadian rhythms; grouping data by *periods* yielded information concerning short-term changes within rest periods, such as sleep. Data was grouped by both *periods* and *cycles* for groups of subjects receiving the same experimental treatment. Only data collected from subjects in which complete body temperature or heart-rate measurements were obtained are included in the data presented here. Mean values for both individual subjects and for groups of subjects receiving the same experimental treatment were plotted as a function of time. Variations in the functions obtained in this manner were visually inspected for trends. Due to the measurement techniques used and the range of individual differences possible with such techniques, the absolute values obtained with the various work-rest schedules cannot be compared.

An analysis of skin temperatures and heart-rate data by *cycles* is presented in Figure 3. For this figure, data collected from individual subjects has been grouped by cycles; then, the mean cycle values for the subjects administered a particular schedule have been plotted. The position of the curves on the Y axis has been arbitrarily shifted so that the details of the functions can be easily studied. Both skin temperature and heart-rate data display circadian (about 24 hours) components. Circadian fluctuations would appear to be the least evident in the heart-rate data obtained from subjects administered the *Schedule 1* (one-half hour rest—one-half hour work) treatment. Given the fact that all experimental sessions started between 4:40 p.m. and 6:28 p.m., the temperature readings appear to drop in the early hours of the morning. A tendency towards temperature increase with an increase in the number of hours the subject has been in the experiment also appears evident. Circadian variations in heart-rate appear to agree with those in the skin temperature data.

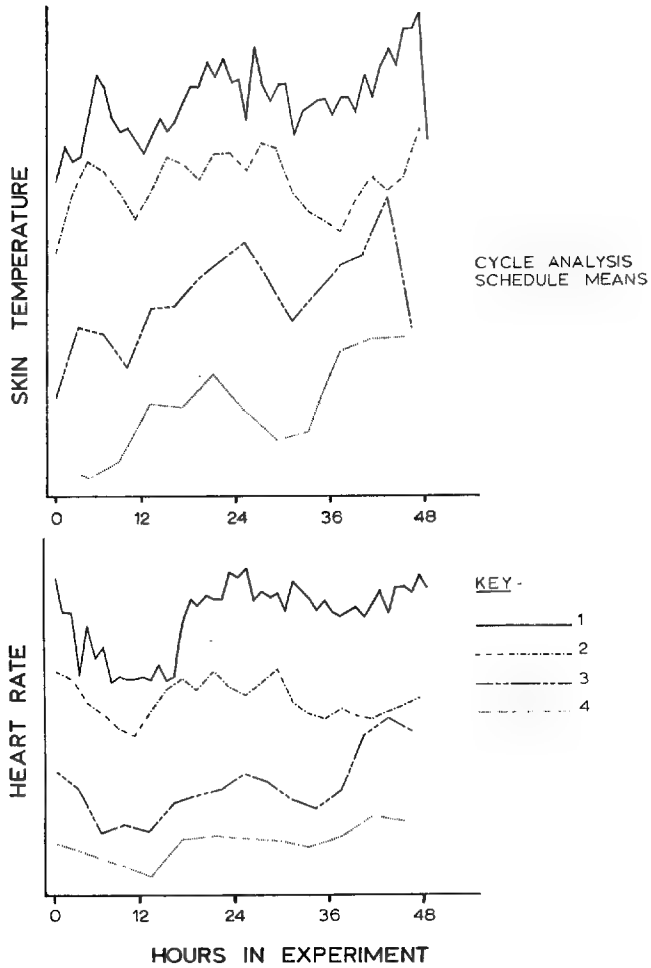


Fig. 3. Cycle Analysis of Skin Temperature and Heart Rate Data.

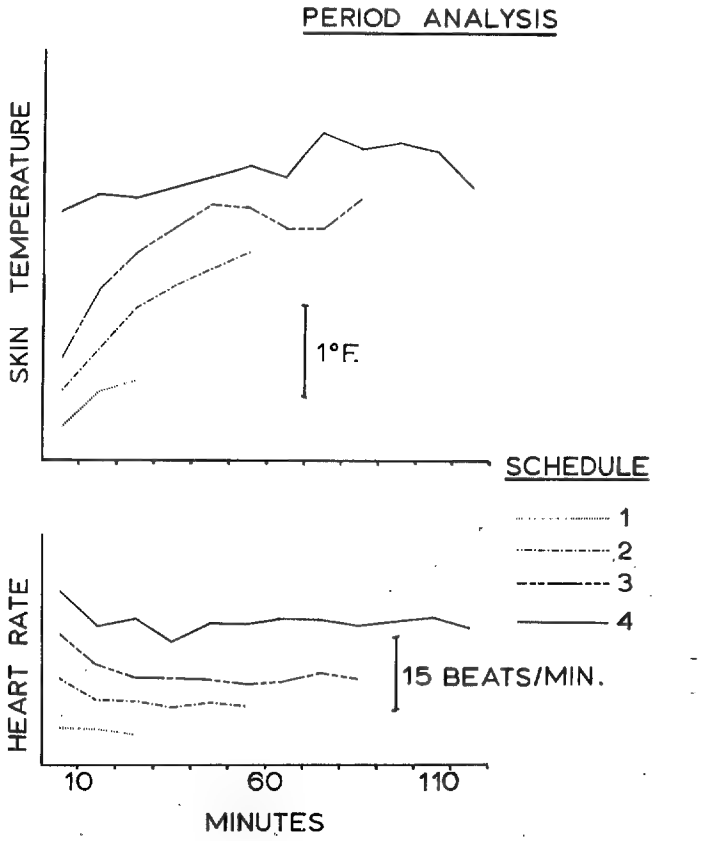


Fig. 4. Period Analysis of Skin Temperature and Heart Rate Data.

An analysis of skin temperature and heart-rate data by *periods* is presented in Figure 4. Data collected from individual subjects has been grouped by periods; then, the mean period values for the subjects administered a particular schedule have been plotted. The position of the curves on the Y axis has been arbitrarily shifted so that the details of the functions can be easily studied. Mean skin temperature varied over a range of less than two degrees Fahrenheit, and skin temperature appears to increase as a function of period. Mean heart-rate varied over a range of less than 15 beats per minute, and heart rate appears to decrease as a function of period. Period variation in mean skin temperature and heart-rate appears to be the least regular for *Schedule 4* data.

DISCUSSION

The results of the present study indicate that a comfortable harness-mounted skin temperature sensor can be designed and used to monitor isolated active subjects over an extended time. The increased skin temperature readings obtained with a *period* analysis is similar to mean skin temperature changes observed in resting man by Kreider, et al.[9] Similarly, the circadian temperature and heart-rate changes evident in the *cycle* analysis are in agreement with the literature as reviewed by Kleitman.[6] Thus, the data collected display many of the characteristics associated with standard body temperature measures.

The comfort and apparent reliability of the system, together with Russian experience with physiological harness systems, suggest that it may be a promising technique for monitoring body temperature changes remotely for periods of weeks or more. Despite the positive nature of these results, a number of important questions remain unanswered. Harness skin temperature measures should be compared with concomitant oral, rectal, and room temperature measures under a wide range of conditions. The medical diagnostic and prognostic value of this body temperature measure must be determined if such measures are to be considered for inclusion in any future aerospace monitoring systems.

A number of significant independent variables have been related to changes in body temperature. Work,[11,12] food intake,[6,7] heating,[4] exposure to cold[8] and sleep[6,7] all result in a significant variation in body temperature. Unfortunately, the nature of these variations has been shown to be a function of the way in which body temperature is measured. Thus, for example, when men rest or sleep, mean weighted skin temperature increases while rectal temperature decreases.[9] Parametric studies, relating the above identified independent variables to the harness-mounted temperature sensing techniques, should be conducted.

Kleitman[5] and others[10] have demonstrated a significant parallelism between body temperature circadian variations and both physical and mental performance. Thus, body temperature might be used as a simple measure of alertness, efficiency, and other related behavioral performance factors. Unfortunately, this relationship has been demonstrated with oral and rectal measures, but little is known about the relationship between skin temperature measures and performance. In the present study, temperature measurements were made only during the rest periods. Additional research is needed in which these temperature measurements are made during the performance of appropriate behavioral tasks to evaluate the potential relationship between this skin temperature measure and performance.

ACKNOWLEDGMENT

The technical assistance of the following personnel is gratefully acknowledged: M. Blaug, R. Hiss, R. Jacob, J. Siegfried, S. Tepas, and W. Tryon.

REFERENCES

1. Agadzhanyan, N. A., Akulinichev, I. T., Zazykin, K. P., and Maksimov, D. G.: A Method of Fastening Electrodes for Registering an Electrocardiogram During Manned Space Flights. Problems of Space Biology, Volume I. Edited by N. M. Sisakyan. NASA TT F-174, November 1963.
2. Alnutt, R. W., Weinberg, P. T., and Barbiere, R. E.: Techniques of Physiological Monitoring, II. Components. Rpt. No. AMRL-TDR-62-98 (II). Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio.
3. Berry, C. A.: Acromedical Preparations. Mercury Project Summary including results of the Fourth Manned Orbital Flight, May 15 and 16, 1963. NASA SP-45, October 1963.
4. Hertzman, A. B.: Regulation of Cutaneous Circulation During Body Heating. Temperature; It's Measurement in Science and Industry, Volume 3, Part 3. Edited by J. D. Hardy. New York: Reinhold, 1963.
5. Kleitman, N.: Studies on the Physiology of Sleep: VIII. Diurnal Variation in Performance. *Am. J. Physiol.*, 104:449, 1933.
6. Kleitman, N.: Sleep and Wakefulness; Revised and Enlarged Edition. Chicago: Univ. Chicago Press, 1963.
7. Kreider, M. B., and Buskirk, E. R.: Supplemental Feeding and Thermal Comfort During Sleep in the Cold. *J. Appl. Physiol.*, 11:339, 1957.
8. Kreider, M. B., and Iampietre, P. F.: Oxygen Consumption and Body Temperature During Sleep in Cold Environments. *J. Appl. Physiol.*, 14:765, 1959.
9. Kreider, M. B., Buskirk, E. R., and Bass, D. E.: Oxygen Consumption and Body Temperatures During the Night. *J. Appl. Physiol.*, 12:361, 1958.
10. Loveland, N. T., and Williams, H. L.: Adding, Sleep Loss, and Body Temperature. *Percept. mot. Skills*, 16:923, 1963.
11. Minard, D., and Copman, L.: Elevation of Body Temperature in Health. Temperature; It's Measurement in Science and Industry, Volume 3, Part 3. Edited by J. D. Hardy. New York: Reinhold, 1963.
12. Selle, W. A.: Body Temperature; Its Changes with Environment, Disease, and Therapy. Springfield: Charles C Thomas, 1952.
13. Tepas, D. I.: Some Relationships Between Behavioral and Physiological Measures During a 48-hour Period of Harassment; A Laboratory Approach to Psychological Warfare Hardware Development Problems. Proceedings of the First Symposium on Psychological Effects of Non-Nuclear Weapons. 1:112, 1964.
14. Tepas, D. I., Jacob, R. H., and Blaug, M.: A Direct-wire System for Recording Electrophysiological Data Continuously From Man Over Extended Time Periods. Proceedings of the Fifth National Symposium on Human Factors in Electronics. pp. 110-112, 1964.

60-Day Exposure to Artificial Atmospheres

FRED N. ZEINER, PH.D.

Three laboratory species were subjected to elevated oxygen tensions for 60-day periods, with nitrogen at either high or at minimal levels. No influence of the nitrogen could be detected. At 337 mm. oxygen with hamsters and 373 mm. with mice there was no increase in mortality, either during the exposure or following return to the normal altitude environment of Denver. Lung damage was seen, however, at the 300 mm. level and became more severe as oxygen tension was further increased. Rats are more tolerant of elevated oxygen than are mice or hamsters, no lung changes being detectable at the 300 mm. level. It is concluded that higher oxygen tensions may be withstood, and for longer periods, than previously reported.

COMPOSITION of an artificial atmosphere that will be satisfactory for prolonged space habitation interests both physiologist and engineer. Problems are antagonistic requiring a reasonable compromise. Low total pressure and absence of inert gas ease engineering problems, but an oxygen tension above minimal physiologic requirements provides a margin of safety in the advent of emergency leakage. The upper limit of oxygen for periods in excess of three or four weeks is unknown. Need of an inert gas has not been demonstrated,[6] but without this determination any effects seen in 100 per cent oxygen, whatever the tension employed, might be attributed to lack of inert gas rather than to the level of oxygen. Any effect of nitrogen lack has been questioned,[8] but loss of many animals early in their exposure, or following return to normal atmosphere, clouds the result. The possibility of atelectasis must always be considered in absence of inert gas.

Much work has indicated that exposure for more than a few hours to oxygen tensions above 425 mm. Hg produces toxic symptoms; thus, 425 mm. can be considered the maximum.[1,2,3,5,7,9,10,11] The higher the tension of oxygen about 425 mm., the sooner and the more severe are toxic symptoms. Although some have concluded that tensions less than 425 mm. can be tolerated indefinitely,[3,10,11] this seems unwarranted, being based on exposures of only from 24 hours to seven days. It appears more probable that a time/tension relationship exists below as well as above the limit of 425 mm.; this has been suggested.[12] The data available for such a curve cover only three or four weeks which represent a very short period of a man's life-time. Further, the longer exposures have been at near minimal physiologic levels. A variety of end-points of detriment complicates construction of a time/tension curve of oxygen tolerance and exposure. Testing for much longer periods to tensions higher than sea-level conditions, but below 425 mm. must be done before a satisfactory time/tension relationship can be demonstrated.

The relatively long-term work mentioned has been done on man and at minimal oxygen tension. Longer exposures and those involving higher oxygen tensions must be tried first on experimental animals. Such a beginning has been made on mice.[8] Direct extrapolation of findings from experimental forms to man cannot be made, but objectivity of results and lack of risk to human welfare justify preliminary work. Also, in terms of normal life-span, periods of exposure of laboratory animals can be of highly significant duration.

Three species have been used in the reported work to provide a better basis for extrapolation to humans. Sixty-day exposure represents a significant fraction of the expected life-span of these species. An attempt was made to evaluate the effect, if any, of normal versus minimal levels of nitrogen with constant oxygen level. Since no differences were seen in the earlier series, this phase was discontinued in later work. Oxygen tensions employed have been between the known minimal level and the maximal for short periods.

METHODS

Rats, mice, and hamsters have been subjected to experimental atmospheres for 60-day periods. Young adults were used, female with the exception of series 4-6. Through series 18 animals were divided into three groups; controls were pumped air at ambient pressure, one group was supplied with oxygen at reduced pressure, and the third group received an oxygen-nitrogen mixture which provided, at ambient pressure, a partial pressure of oxygen essentially the same as for those receiving only oxygen. Results to this point were such that the oxygen-nitrogen groups were omitted in later work (series 19-28) and only mice were used.

Compressed gas was dry; air for the appropriate groups was pumped through anhydrous calcium chloride before delivery to the chambers. Rate of gas flow was much more than adequate to assure metabolic oxygen. Excess flow helped to reduce levels of water vapor, carbon dioxide, and ammonia.

In the first nine series containers of soda-lime were placed in the chambers to reduce carbon dioxide levels. Gas analysis showed this to be inefficient and in later series the atmosphere of each chamber was recirculated through containers of sulfuric acid and of soda-lime for better removal of metabolic by-products.

Transversely bissected, galvanized hot-water tanks served as chambers. The open ends were closed with

From the Department of Zoology, University of Denver, Denver, Colorado. Support for this study was provided by the Martin Company, Denver Division, The Faculty Research Fund of The University of Denver, and NASA Research Grant No. NsG-518.

logic mechanisms, but prompts a cautious approach to drawing general conclusions applicable to all mammalian species including man on the basis of the experiments reported here on mice.

Fortunately, it is now possible to say that similar studies have been completed using rats and guinea pigs. Preliminary analyses of the data show some randomness in the pressure-ratio figures and, in general, similar trends in blast tolerance with variations in the ambient pressure. Whether or not the pressure-ratio associated with such experiments is indeed a constant, with the differences noted indicating only "normal" experimental error and chance variations, cannot be stated now. But if results from future experiments with other species indicate that the LD_{50}'s can be expressed as multiples of the initial pressure, biological blast scaling as a function of ambient pressure will become a relatively simple matter. For example, man's tolerance (LD_{50}-24-hours) to "sharp"-rising overpressures of 400-msec duration has been calculated to be 50 psig from extrapolation of an interspecies correlation involving six different mammals.[10] Since the data were compiled at an ambient pressure of 12.0 psia, the overpressure—normalized to the initial pressure—would be 4.2 atm. Consequently, to obtain the LD_{50} for "long"-duration air blasts for different ambient pressures, one may tentatively multiply the ambient pressure of interest by 4.2. Thus at sea level (14.7 psia), the calculated LD_{50} for man would be 62 psig; at 26,400 ft (5.2 psia) it would be 22 psig. It is well to emphasize the tentative and uncertain nature of these procedures, and it is no doubt premature to dwell on this topic further. Let it suffice to say that full understanding of biological blast scaling must await the results of future work.

Be this as it may, it is currently quite clear that the ambient pressure is indeed a physical parameter of major importance in specifying blast effects. Consequently, recording the local barometric pressure now needs to be considered a requirement in all quantitative investigations of blast tolerance.

ACKNOWLEDGMENTS

The able technical assistance of Mr. Charles S. Gaylord, Mr. Peter A. Betz, Mr. William Hicks, Mr. Donald E. Pratt, Mr. Dennis D. Branch, Mr. Kabby Mitchell, Jr., Mr. Keith G. Saunders, and Mr. Raymond T. Sanchez is greatly appreciated. Also, the aid of Mr. Robert A. Smith, who prepared the illustrative material, Mr. Ray W. Albright, who carried out the probit analysis on a Bendix G-15 electronic computer, and Mrs. Maxine U. Thibert, who assisted with the illustrations, typed and edited this report, is acknowledged.

REFERENCES

1. Benzinger, T.: Physiological Effects of Blast in Air and Water. In *German Aviation Medicine, World War II*, Vol. II, Chapter XIV-B, pp. 1225-1259, U.S. Government Printing Office, Washington, 1950.
2. Bleakney, W., Weimer, D. K. and Fletcher, C. H.: Shock Tube: A Facility for Investigations in Fluid Dynamics. *Rev. Sci. Instrum.*, 20:807-815, 1949.
3. Clemedson, Carl-Johan, and Hultman, H.: Air Embolism and the Cause of Death in Blast Injury. *Milit. Surg.*, 114:424-437, 1954.
4. Finney, D. J.: *Probit Analysis. A Statistical Treatment of the Sigmoid Response Curve* (Second Edition). Cambridge: University Press, 1952.
5. Fisher, R. B., Krohn, P. L., and Zuckerman, S.: The Relationship Between Body Size and the Lethal Effects of Blast. Report R. D. 284. Ministry of Home Security, Oxford, England, Dec. 10, 1941.
6. Granath, B. A., and Coulter, C. A.: BRL Shock Tube Piezo-electric Blasts Gages. BRL Technical Note No. 1478, Ballistic Research Laboratories, Aberdeen Proving Ground, Md., August 1962.
7. Haber, F., and Clamann, H. G.: Physics and Engineering of Rapid Decompression: A General Theory of Rapid Decompression. Report 3, Project 21-1201-0008, USAF School of Aviation Medicine, Randolph AFB, Tex., 1953.
8. Lampson, C. W.: Résumé of the Theory of Plane Shock and Adiabatic Waves with Applications to the Theory of the Shock Tube. BRL Technical Note No. 139, Ballistic Research Laboratories, Aberdeen Proving Ground, Md., March 1950.
9. Luft, U. C., and Bancroft, R. W.: Transthoracic Pressure in Man During Rapid Decompression. *J. Aviat. Med.*, 27:208-220, 1956.
10. Richmond, D. R., Clare, V. R., Goldizen, V. C., Pratt, D. E., Sanchez, R. T., and White, C. S.: Biologic Response to Overpressure II. A Shock Tube Utilized to Produce Sharp-rising Overpressures of 400 Milliseconds Duration and Its Employment in Biomedical Experimentation. Technical Progress Report No. DASA 1246, Defense Atomic Support Agency, Department of Defense, Washington, April 7, 1961. Also *Aerospace Med.*, 32:997-1008, 1961.
11. Richmond, D. R., and White, C. S.: A Tentative Estimation of Man's Tolerance to Overpressures from Air Blast. *Proceedings of the Symposium on Effectiveness Analysis Techniques for Non-Nuclear Warheads Against Surface Targets, October 30-31, 1962*, Vol. I, pp. L to L-34, U.S. Naval Weapons Laboratory, Dahlgren, Virginia. Also published as Technical Progress Report No. DASA 1335, Defense Atomic Support Agency, Department of Defense, Washington, November 7, 1962.
12. Richmond, D. R., Goldizen, V. C., Clare, V. R., and White, C. S.: The Overpressure-duration Relationship and Lethality in Small Animals. Technical Progress Report No. DASA 1325, Defense Atomic Support Agency, Department of Defense, Washington, September 10, 1962.
13. Richmond, D. R., Goldizen, V. C., Clare, V. R., Pratt, D. E., Sherping, F., Sanchez, R. T., Fischer, C. C., and White, C. S.: Biologic Response to Overpressure. III. Mortality in Small Animals Exposed in a Shock Tube to Sharp-rising Overpresures of 3 to 4 msec Duration. Technical Progress Report No. DASA 1242, Defense Atomic Support Agency, Department of Defense, Washington, June 15, 1961. Also *Aerospace Med.*, 33:1-27, 1962.
14. Richmond, D. R., Taborelli, R. V., Sherping, F., Wetherbe, M. B., Sanchez, R. T., Goldizen, V. C., and White, C. S.: Shock Tube Studies of the Effects of Sharp-rising, Long-duration Overpressures on Biological Systems. Report SWR-TM-59-2, pp. 171-194. Proceedings of Third Shock Tube Symposium, Air Force Special Weapons Center, March 10-12, 1959. Also published as Technical Progress Report, TID-6056, U.S. Atomic Energy Commission, March 10, 1959.
15. White, C. S., Chiffelle, T. L., Richmond, D. R., Lockyear, W. H., Bowen, I. G., Goldizen, V. C., Merideth, H. W., Kilgore, D. E., Longwell, B. B., Parker, J. T., Sherping, F., and Cribb, M. E.: The Biological Effects of Pressure Phenomena Occurring Inside Protective Shelters Following Nuclear Detonation. Report WT-1179. Operation Teapot. U.S. Atomic Energy Commission, October 28, 1957.

Current Concepts and Practices Applicable to the Control of Body Heat Loss in Aircrew Subjected to Water Immersion

CAPT. E. L. BECKMAN, MC, USN, CDR. E. REEVES, MSC, USN, AND R. F. GOLDMAN, PH.D.

The problem of providing adequate clothing for personnel who either accidentally or otherwise are immersed in cold water has continued to challenge clothing manufacturers for the past decade. The development of foamed plastics and other clothing materials offers new possibilities. Likewise new advances in energy conversion systems offer new solutions to this critical operational problem.

The basic physical and physiological concepts which pertain to the problem of limiting thermal loss from the immersed human are reviewed. The newer technical developments in insulative clothing and supplemental heating systems are reviewed and discussed with relation to these basic concepts.

IMMERSION IN COLD WATER is one of the major environmental hazards to which military personnel may be exposed. To the ground-based pilot and crew, it poses only a remote and little considered hazard, but to carrier-based flying personnel it is an ever present threat to existence. There is no conditioning program effective in altering the unpleasantness of the experience or in decreasing the lethal rate at which a warm body loses heat to the cold water. Conductive heat loss from the immersed nude body occurs at all water temperatures below that of the immersed body. When water temperature reaches 24° C, death from body heat loss for unprotected personnel must be anticipated within 24 hours. At lower water temperatures, critical failure of thermal balance will occur in a few hours or even in minutes if immersion occurs in freezing sea water. Thus, any situation, accidental or otherwise, in which personnel are immersed in cold water for any appreciable time requires provision for conserving body heat. The following methods for limiting the rate of heat loss from the immersed human body are presently practiced:

1—utilizing the body's own protective thermal mechanisms to maximum advantage;

2—limiting the duration of the period of immersion;

3—supplying insulative clothing to reduce heat loss;

4—providing supplementary heat to replace the body's heat loss.

Utilizing the body's own protective mechanisms to the maximum is of primary importance. However, enhancement of the body's tolerance to cold water immersion by training or conditioning, while possible to a limited extent, is of little operational value. It has been established that some long distance swimmers can endure prolonged immersion in cold water as a result of the protection afforded against thermal loss by an increased thickness of their subcutaneous fat layer and also by a conditioning regimen that trains them to swim for long periods of time at a very high rate of metabolic heat production. Carlson, et al.,[1] studied one such swimmer who had spent as long as 14 hours swimming in water between 4 and 8°C; his body fat content was 33 percent of his total body weight and he swam at a heat production rate of 550 Kcal/hr. Pugh and Edholm,[2] studying English Channel swimmers, observed that they too had an increased subcutaneous fat which limited the rate of heat loss and they swam as vigorously as possible to maintain a high rate of heat production. Training to improve the physical work capacity is worthwhile but developing the capability of maintaining a 550 Kcal/hr work output for 8-12 hours can only be achieved after many years of training and is not likely to become a prerequisite for aviation duty. The deposition of excess body fat is contrary to our present military view of physical fitness.

Limiting the time of immersion can be completely effective at all subcorporeal ranges of water temperature. Immersion of an unprotected subject in freezing water is an excruciatingly painful but endurable experience and, judging by the practice of the many "Polar Bear" Clubs, even routine to some individuals. The water "ditched" airman, however, must cope with cold water until rescued, a period that may extend from minutes to hours. Obviously, protecting military personnel against the effects of accidental cold water immersion by controlling the duration of exposure has little operational meaning.

Only the remaining two methods of controlling thermal loss offer any promise of being rewarding from the military point of view. The advances in clothing and textile technology which have occurred within the past 10 years suggest that improved insulative fabrics could be provided. In addition, the newer technologies in energy conversion systems, i.e., thermoelectrics, electrochemistry, and thermionics, etc., suggest that

From the Naval Medical Research Institute, Bethesda, Maryland 20014, and U. S. Army Research Institute of Environmental Medicine, Natick, Massachusetts.

Bureau of Medicine and Surgery, Navy Department, Research Task No. MR005.13-4001.06. The opinions or assertions expressed herein are the private ones of the authors and are not to be construed as official or reflecting the views of the Navy Department or the Naval service at large.

systems for replacement of body heat may be available at an acceptable weight penalty so that it may be possible to maintain immersed personnel in thermal balance for a significant period even in freezing water. It would, therefore, seem appropriate, to review the problem of heat loss and thermal balance of the immersed human; to define the physical and physiological limitations of thermal balance during immersion; to evaluate the advances in insulation and heat replacement methods which would be useful in maintaining the thermal balance of immersed military personnel; and, to attempt to derive a realtistic prediction of what developments should be undertaken in support of the servicemen who may be immersed in cold water.

Man appears to be acutely sensitive to any decrease in body temperature below 95°F (35°C). Although the deep body temperature at which given central nervous system changes occur varies between individuals, on the basis of clinical experience in producing hypothermic anesthesia, McQueen[3] has reported that when the core temperature is decreased to 34°C, amnesia occurs for the period of cooling below that temperature and the patients become dysarthric and begin to lose contact with their surroundings. Pain is generally appreciated down to a core temperature of 30°C at which point the ability to recognize relatives or surroundings is also lost. Voluntary motion is lost at 27°C, as are pupillary light reflexes and deep tendon and skin reflexes. Virtue[4] corroborated these findings and reported that cardiac irregularities such as atrial fibrillation, ventricular ectopic beats, and ventricular rhythms were to be expected at core temperatures of 32-30°C.

While there are these serious effects of whole body hypothermia, the regional heat losses from the fingers and hands have been found to be the practical limiting factor in the effectiveness of many of the garments designed for protection against cooling during immersion. Provins and Clark[5] demonstrated that as the fingers, hands, and arms were cooled below 15.5°C, subjects developed an increased reaction time, a decrease in tracking proficiency and a decrease in manual dexterity, with a loss of tactile discrimination and kinesthetic sensation as well as a decrease in muscle strength. In some of our immersion studies in 10°C water, unprotected subjects demonstrated a decrease in grip strength of 50 percent in less than one hour of immersion.[6]

In order to design a protective system, it is necessary to closely define the temperature limits within which the protective system is expected to function. Although the deep body temperature of 27°C is the critical vital temperature for the sedated, anesthetized patient, the unmedicated volunteer immersion subject appears to become thermally unstable below 34.4°C (94°F) and tends to become poikilothermic. Hence, it would seem to be necessary to limit the heat loss of cold water immersed victims so as to maintain the deep body temperature above 34.4°C if a survival/rescue operation is to be successful.

The water temperature in which the downed aviator must survive varies with the geographical location of the accident, the weather, time of year, and time of day as shown in Table I. Studies in progress at the Naval Medical Research Institute indicate that heat loss is not a critical limiting factor in experimental immersions of 24 hours (nude) in 85°F water, but that it becomes critical for many subjects immersed nude in 75°F water in less than 12 hours.[6] The mean voluntary tolerance time of 24 subjects immersed in 75°F water was 8.3 hours. This is substantially the tolerance time found in actual survival experiences. Therefore, some form of protection is needed for prolonged immersion in water of 75°F and below. From Table I, it can be seen that on the basis of the geographical distribution of ocean areas having a surface temperature below 77°F, there is a 67 per cent probability of an accidental immersion occurring in water requiring some thermal protective garment. In the past the time required for rescue varied from less than 1 to 36 hours. The thermal protection required obviously varies with the duration of the exposure. The temperatures of the oceans of the world vary from that of freezing salt water (—2°C) to the 32°C summer water temperature of the Persian Gulf. Consequently, from the point of view of either a survival or a protective thermobalance system, it is necessary to consider an immersion of 1 to 36 hours in waters varying in temperatures from —2° to 30°C with weather conditions varying from sunshine to storm and in sea states from flat calm to typhoon. Solar radiation is very beneficial in warming the cold water immersed victim whereas the rougher the sea state the greater will be the heat lost to the water moving past the immersed victim and the greater will be his rate of cooling.

TABLE I. TEMPERATURE VARIATIONS IN THE OCEANS

Percentage of Ocean Surface with Temperature Below	Atlantic	Indian	Pacific	Mean
25°C (77°F)	77.6	62.0	59.9	66.7
20°C (68°F)	49.9	48.3	41.6	46.6
Annual Variation Tropical Latitudes		—1°	— 2°C	
Annual Variation Higher Latitudes		—1°	—17°C	
Diurnal Variations		—0.1°	— 0.4°C	

Since weight and space are limiting factors in the design of aircrew equipment, it is necessary to consider the weight and cube of any survival system. The present anti-exposure garments for aircrew weigh 7.5 kg (16.5 lbs); this then should be an acceptable upper limit for any replacement system.

Before considering methods of prevention of heat loss by insulation or replacement of heat loss by supplementary heat, it is first necessary to evaluate the insulative and heat-generating capacity of the body itself. The insulative capacity of the body may be described as both active and passive, e.g.: the active phase of tissue insulation results from the variable peripheral vasoconstriction of blood vessels in the skin and the passive insulation is provided by the thickness of the relatively avascular subcutaneous fat layer. In other words, the insulative effectiveness of the surface of the body is equal to the insulative value of the relatively constant fat layer plus the thickness of the

actively vasoconstricted, and thus insulative layer.

Thermal conductivity measurements made on freshly excised human tissue show that the heat loss through a layer of fatty tissue 1 cm. in thickness is equal to 14.4 K/cal/m²/hr/°C. Similar measurements on excised fresh muscle, revealed a thermal conductivity of 39.6 Kcal/m²/hr/°C/cm thickness. The heat losses of the surface tissue of the body measured *in vivo* at three conditions of body metabolism yielded the following results: (1) when the body is cold, at rest, and not shivering, the heat loss is 9 Kcal/m²/hr/°C; (2) when the body is cold, at rest, but shivering, the heat loss is increased to 13 Kcal/m²/hr/°C; (3) when the body is warm and exercising, the heat loss from the skin is 50 Kcal/m²/hr/°C. The thermal transfers of the skin and subcutaneous tissues of an obese long distance swimmer have been observed to vary from 2.2 Kcal/m²/hr/°C for the resting condition in 10°C water, up to 33 Kcal/m²/hr/°C in 36°C water.[7] These extremes in insulative values reflect the skinfold thickness and the variation in depth of chilling and degree of vasoconstriction due to the cold stimulus. The difference between the measurements obtained on excised tissue and those obtained *in vivo* primarily represents the effects of blood flow. It may be assumed that the thermal conductivity of the combined skin, subcutaneous and fat tissues cannot be less than that of the fat layer, i.e., 14 Kcal/m²/hr/°C/cm. Observed values of heat loss from the intact body less than this, i.e., 2.2 to 9 Kcal/m²/hr/°C imply a mean thickness of the insulative layer greater than 1 cm. These data indicate that: (1) the fat man will be better protected than his thin counterpart; (2) the thermal conductivity and thus the insulative value of the body surface layer may vary 20 fold* for different persons; and, (3) the highest insulative value will be provided by a cold, vasoconstricted skin with a thick subcutaneous fat layer. From these data it may further be inferred that a fat and a thin man will require different amounts of external insulation to protect them equally. Furthermore, it appears that the protective system should be designed to keep the skin cold and vasoconstricted for optimal efficiency of the insulative and heating systems of the body.

Thermal balance in the unprotected man is controlled not only by the rate of heat transfer through the externally cooled tissue, but also by the ability of the body to produce heat. Increase in the heat production of a body immersed in cold water is based upon both involuntary and voluntary thermogenesis where involuntary thermogenesis is the heat produced by involuntary shivering, increased muscle tonus, and by non-shivering thermogenesis subsequent to cold acclimatization; active thermogenesis is voluntary muscular effort. The oxygen consumption rate of nude subjects immersed in 10°C water varies from 2.2 times his resting metabolic rate for the obese subject up to a maximum of 9 times his resting rate for the tall lean subject.[6]

The energy requirements of a 70 kilogram man for various activities have been enumerated by Morehouse and Miller.[8] Such a subject, swimming the crawl stroke at 1 MPH, would expend 410 Kcal/hr; he would expend 420 Kcal/hr while swimming the breast stroke at the same rate. This heat production would certainly be useful in maintaining body temperature if it could be maintained. However, this amount of physical activity cannot be continued for an 8 to 10 hr. period by any but the most practiced swimmer. Trained frogmen, while swimming, are expected to maintain a work rate of only 200 Kcal/m²/hr which would be about 380 Kcal/hr for the 70 Kgm. man. The trained, long distance underwater swimmer, studied by Hunt, Reeves, and Beckman[9] produced only 260 Kcal/hr while swimming with swim fins at a speed of 1.1 MPH during a 5-hour underwater swim.

The practical value of increased energy expenditure with respect to the ability to endure prolonged immersion has been investigated by Beckman and Reeves,[10] who studied the physiological effects of immersion of 24 nude subjects in 24°C (75°F) water for up to 12 hours. Although only 2 of their experiments had to be terminated because of a decrease in core temperature to below 35°C (95°F), 16 subjects failed to complete the 12-hour immersion owing to severe, persistent muscle cramps and other effects attributable to physical exhaustion. Thus the practical solution appears to be in increasing the insulation. These investigators also related the specific gravity of their subjects, and as a corollary, total body fat (estimated with respect to a 14% standard reference body) to mean energy expenditure during the period of immersion. As shown in Figure 1, the short fat subject with the lowest specific gravity expended only 70 Kcal/m²/hr during a 12-hour immersion. However, the tall thin subject with the

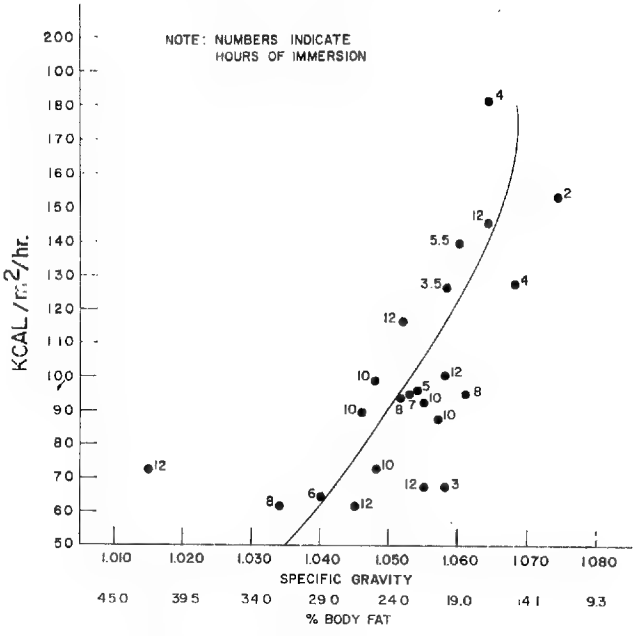


Fig. 1. Relationship of rate of heat loss vs. body specific gravity in 23 nude subjects immersed to neck level in 75°F. water.

*The insulative value, K_I, is the reciprocal of the thermal conductivity described in Kcal/m²/hr/°C.

highest specific gravity while producing 137 Kcal/m²/hr during the two hours he remained in the water experienced a drop of deep body temperature to below 95°F. The uppermost data point on the line of best-fit represents a subject who also had to be taken from the pool within 4 hours owing to a decline of core temperature below 95°F. Between the extremes of the man with the thick, insulative, adipose layer and the two thin men with high specific gravities are data points representing the other subjects. A few of these subjects with high specific gravities were athletic by habit, and were able to maintain their body heat by continuous exercise for a twelve-hour period, even though they had a relatively thin adipose layer.

Some subjects in this series developed circulating blood glucose levels of 50-60 mgm percent and experienced a typical hypoglycemic episode. Some of these subjects were given brandy or hot coffee containing much sugar after they had declared that they could no longer endure the experiment. In most cases, these subjects then continued and were able to extend their tolerance times by one or two hours. Although no critical studies have been carried out, it is our impression that most subjects who had been given nothing by mouth during the immersion tests, extended their tolerance times when given food or brandy. The judicious use of food to increase metabolism by the "specific dynamic action of food"[11] and of brandy to decrease muscular rigidity, cramps and discomfort warrant further experimentation.

It is apparent that the inherent insulation of the body and the capacity of the body to produce heat both vary widely between individuals. It would be futile to depend upon such uncertain devices for protection against thermal heat loss during immersion. Even maximum values of both parameters are inadequate to protect the individual in 40-50°F (4-10°C) water. It is therefore necessary to consider the use of external insulative systems to limit the loss of any heat which is produced by the body.

The value of an insulative system depends upon: (1) the insulative value of the external insulation plus the insulation of any still layer at the body surface; (2) the geometry of the body to be insulated; (3) the temperature difference between the body surface and the surrounding water; and (4) the rate of flow of the water.

In general, a vacuum layer, or a still air layer, would provide the best thermal protection but these layers are difficult to provide in flexible garments. Consequently, something less than ideal must be accepted. Theoretically, optimal clothing material, represented by uncompressed wool or by foamed neoprene, provides approximately 1.6 CLO* of insulation/cm thickness, or 4 CLO/inch. During World War II, considerable effort was expended in investigation of the problems of clothing for Arctic based troops.[12] It was found that clothing with a thermal insulation of 4 CLO was necessary for protection but weighed 30 pounds. This amount of insulation could not be provided to the hands and feet and thus even this very thick, heavy clothing did not provide adequate protection. The difficulty in providing adequate thermal protection for the hands and feet relates to the geometry of the part to be insulated. The importance of this factor in insulation is summarized by van Dilla, Day, and Siple.[13] Insulative values of materials are normally described in terms of flat surface insulation. Although the insulative value of material on a flat surface is directly related to its thickness, the relationship is not as simple on shapes like cylinders and spheres. The relationship of thickness of fabric in inches to the effective insulation in CLO is seen in Figure 2. On the bottom line of this graph it is seen that as the thickness of the insulative fabric surrounding a ½ inch sphere is linearly increased, the insulative value increases only slightly and no significant increase in insulative value is provided by increasing fabric thickness beyond 1 inch. The insulative effect of increasing the thickness of the insulative fabric around a cylinder of ½-inch diameter is only slightly better than for a sphere. This figure illustrates why it is difficult, if not impossible to pro-

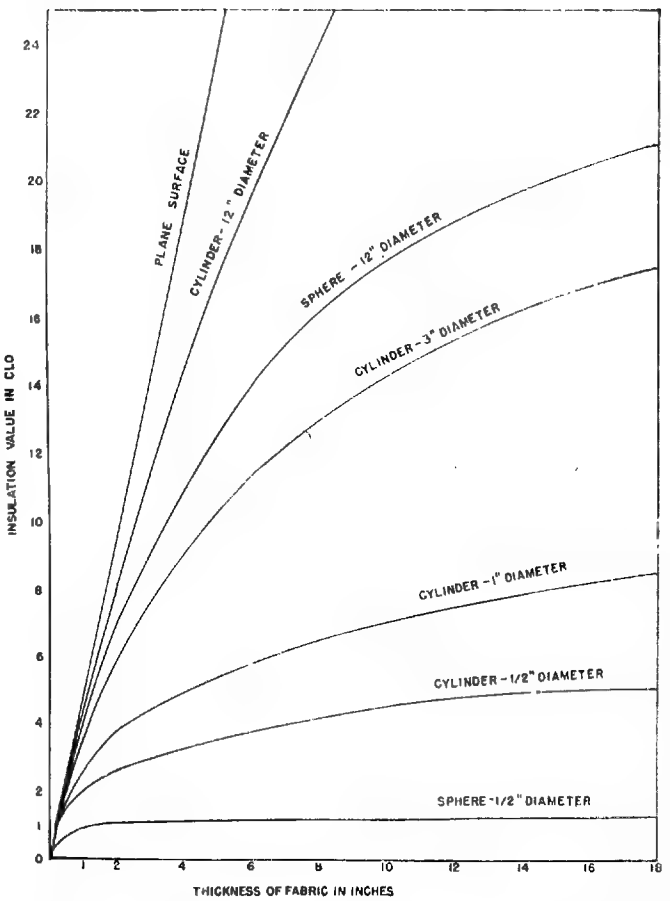


Fig. 2. Insulation of ideal fabric on a plane, cylinders and spheres.

*CLO: The CLO is an arbitrary unit of insulation and is the amount of insulation necessary to maintain comfort at a mean skin temperature of 33.3°C in a room at 21°C with air movement not over 10 ft/min., humidity not over 50 per cent, and a body metabolism of 50 Kcal/m²/hr. On the assumption that 76 per cent of the heat is lost through the clothing, a CLO may be defined as the amount of insulation that will allow the passage of 1 Kcal/m²/hr with a temperature gradient of 0.18°C between the two surfaces.

vide adequate insulation for thin cylinders such as fingers and toes. It has long been known that it is almost impossible to provide adequate insulation in the form of gloves for the fingers and hands in extremely cold Arctic weather. For this reason, mittens rather than gloves have been provided so that the fingers and hands may be made into a ball to improve their surface to mass ratio. A theoretical solution proposed by van Dilla, et al.,[13] to the problem of providing adequate insulation for Arctic troops is shown in Figure 3. The problems which must be solved to provide adequate thermal insulation for Arctic troops in —50°C weather with a 30 knot wind are equal in magnitude to those of providing adequate thermal insulation for personnel immersed in freezing water.

During World War II, many types of thermal insulative garments were developed for protection against heat loss during immersion. These garments all utilized the "dry suit" concept of wrapping the subject in a waterproof bag. Although sound in principle, this is almost impossible to achieve in practice. When waterproof suits for immersion protection of Navy fliers were developed after World War II, they were effective but were also hot, humid, bulky, and unpopular. The insulative value of these garments in air can be easily controlled by varying the thickness of the insulation worn beneath the suit. However, when the insulative layers of such suits are compressed by the water pressure during immersion, the insulative value of the garment is significantly reduced. The MK5A anti-exposure suit for Naval aviators, consisting of a rubberized outer garment and insulative inner layer, is a "dry-suit" of this type with an effective insulation, in air of 2 CLO.[14] When the garment assembly was tested in water the effective insulation was only 0.57 CLO (See Table II). A most serious disadvantage of this type of garment is that if it is torn or leaks because of fabric age or wear, the insulative value then approaches that of still water. An even more serious drawback to the "dry" type of anti-exposure garment results from the normal physiological processes of the body. Immersion in water up to the neck level has been shown by Beckman and DeForest[15] to produce a profound and continuing diuresis of such urgency as to rapidly convert the so-called drysuit to a very wet one.

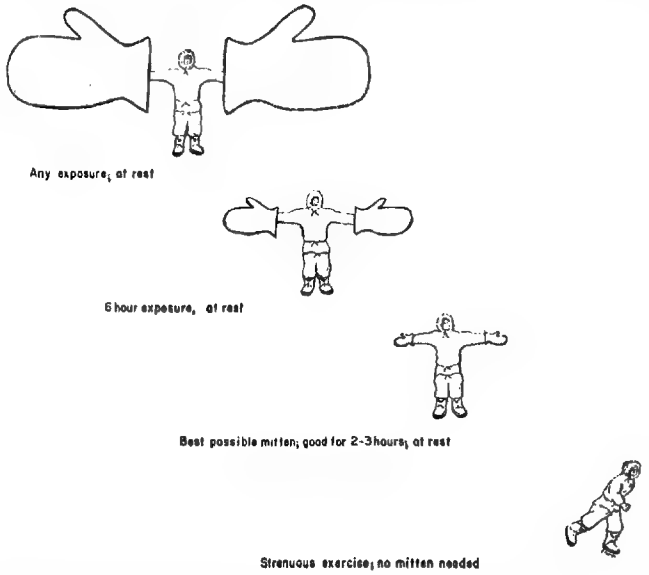


Fig. 3. Relative size of mittens needed for different exposure times at –20°F.

From Van Dilla, M., R. Day and P. A. Siple, p. 384 'Special Problem of the Hands," "Physiology of Heat Regulation and the Science of Clothing," L. H. Newburgh, W. B. Saunders Co., Philadelphia, 1949.

TABLE II. TOTAL INSULATING VALUES OF CLOTHING ASSEMBLIES MEASURES ON A COPPER MAN[14] IN AIR AND WATER (CLO UNITS)

Suit	Air	Still Water	Water Flow 1gpm/250gal	Stirred Water
Nude Copper Manikin	0.62	0.14	——	0.11
MK5A Anti-Exposure Suit	2.05	0.56	0.57	——
Underwater Swimmers Wetsuit (¼" Foamed Neoprene)	1.48	0.76	0.77	0.71
Underwater Swimmers Wetsuit (3/16" Foamed Neoprene)	1.32	——	0.78	——

During World War II, C. R. Spealman of the Naval Medical Research Institute developed the concept of using "spongy" neoprene for insulation in a waterproof boot.[16] The insulative value of such boots were established by laboratory experiment and recommended for use in preventing the "immersion foot" of immersed shipwrecked survivors. Subsequently, an equally significant advance in thermal insulative garments for immersed personnel was achieved when Dr. Hugh Bradner[17] in 1951 reported on his experiments with *unicellular foamed neoprene* garments for thermal insulation of immersed subjects and recommended the use of a tailored suit of unicellular foamed neoprene for underwater swimmers. Since then, such unicellar foamed neoprene "wetsuits" have been adopted by underwater swimmers and "scuba" divers throughout the world. They have proved to be entirely effective for use in water of moderate temperature but less effective in freezing water.

Experiments have been conducted at the Naval Medical Research Institute to evaluate the use of a 3/16 and ¼ inch thick unicellular foamed neoprene suit for thermal insulation and protection for downed aviators.[18] In general, it was found that subjects immersed to neck nevel in 10°C water and wearing 3/16 inch neoprene foamed trousers, jacket, boots, and gloves, were able to tolerate the immersion for approximately 4 hours at which time their great toe temperatures had decreased to near water temperature. When the subjects were exposed to 4.4°C water while wearing the same garments, they were, in general, only able to tolerate 2 hours of immersion. When the subjects were immersed in freezing salt water at a temperature of —2°C, the immersion periods were decreased to 1.3-1.5 hours. Loss of heat from the toes and heels of the feet and from the fingers of the hands, with subsequent pain at temperature levels of 7-8°C limited the exposure

times in most of these experiments. In only a few subjects did body core temperature decrease to a critical level (35 C) before the extremities cooled to the critical level of 8 C.

The theoretical, flat surface thermal insulation of unicellular foamed neoprene is 1 CLO for a ¼-inch thickness of fabric. Experiments on the effective insulation of such a suit was 0.77 CLO.*[11] (See Table II). The effect of increasing the velocity of the water past the manikin is also demonstrated by the data in Table II where it is shown that the effective insulation on the ¼-inch neoprene wetsuit was decreased from 0.77 CLO to 0.71 by slightly increasing the rate of flow of the water. Theoretically, a one-inch thick suit of foamed neoprene with an equal thickness of boots and gloves would be adequate to protect the immersed survivor or swimmer indefinitely in 0 C water. When subjects were clothed in such a bulky suit, it was found that they increased their voluntary immersion time in 4.4 C water to 5 hrs as compared to 2 hours when clothed in a 3/16-inch neoprene garment. While this garment, which weighed 40 lbs and severely restricted the motion of the subject, adequately protected the deep body temperature of the subject, the hands and feet cooled to pain temperatures and constituted the limiting parameters. These experimental results suggest that the required insulation for the extremities had not been achieved and that, within an 8 hour period, heat loss from the extremities will be such as to limit safe exposure to water at temperatures below 12 C at which temperature tissue damage is produced.[13] Therefore, it becomes necessary to consider some method of replacing heat in order to provide thermal protection to the subjects immersed in cold water. It is obviously not possible to rely solely on a thermal replacement system. It is necessary both to insulate the body against the external cold environment and to provide additional replacement heat over the critical areas where the geometry of the body tissues is contrary to the best interest of heat conservation. Goldman[19] came to a similar conclusion as a result of investigation on protective garments for inactive Arctic troops.

Since the advent of the space era, there has been an ever increasing need for more efficient power conversion systems for space vehicles with the result that there have been many significant developments in these technical fields over the past few years. These developments have resulted in systems with more advantageous power/weight ratios, to a point where they may now be considered for use as a primary power source for personnel heating systems. Energy conversion systems can be compared on the basis of several important factors: theoretical energy/weight ratio; system energy/weight ratio; system power/weight ratio; shelf life; cost in terms of power delivery; availability; and, controllability. Collectively, these factors determine the usefulness of the system.

A satisfactory energy conversion system is only one part of the problem of replacement heating. Not only must energy be provided, but the energy must be converted into heat and this heat must be distributed from the area where it is generated to the area of need. Thus, both a useful energy conversion system and a compatible energy distribution system are required to provide supplementary heating. The resistance-wire, electrically heated garment represents the most readily available system of heat generation and distribution. In this system, the energy is converted into heat throughout the distribution of the resistance elements so that area heating can readily be controlled. The resistance-wire electrically heated suit has had several periods of popularity in the military services. An electric-wire heating garment was developed for use by helium-oxygen divers even before World War II. Similar garments were adapted for use by flight crews during World War II. These systems met the need for replacement heating, but the techniques of manufacture left much to be desired and short circuits and "hot spots" were common experiences so that the use of these garments was discontinued after the operational urgency was ended.

More recently, scientists at the R.A.F. Institute of Aviation Medicine, Farnborough, England, together with an engineering firm,* have developed a technique for weaving a fabric in which the resistance-wires are woven between the synthetic fiber threads to form a stretchable garment. Figure 4 shows a glove woven

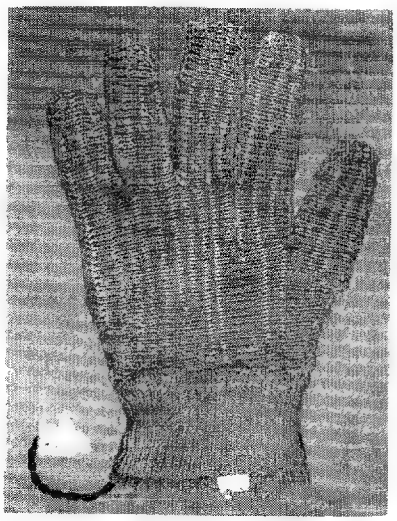


Fig. 4. A heated glove woven with the white insulated wires showing in the fabric.

with the white insulation of the wires showing in the fabric. Gloves, socks, and a coverall type garment of this material were developed for supplying heat to aircrew of inadequately heated aircraft.

Electrically heated Arctic thermal boots and gloves have been developed by the U. S. Army and provide supplemental heating at a power rate of 10 Watts for each boot and glove. The 6-8 hour battery packs used weigh 7 lbs. and are designed to provide protection at —40 C for the inactive Arctic soldier.[21] When constructed with waterproofing techniques, such garments could be used to provide supplemental heat to underwater swimmers or to aircrew of ditched aircraft. On

*Vacuum Reflex Limited, 2 C Hanbury Road, Tottenham, London N. 17, England.

the basis of the previously described experiments on the use of a 1 inch unicellular foam neoprene suit, it would seem that supplemental heat supplied only to the feet and hands would significantly increase the tolerance time to immersion. On the basis of the experiments described above, it seems probable that the most effective type of immersion suit could be achieved by a one inch thick, foamed neoprene suit with the thick neoprene boots and gloves incorporating resistance-wire woven socks and gloves and supplied with a battery power source to provide local heat. Although such a suit might protect the immersed victim in waters at the temperature of freezing sea water for a period of 12 hours, it would weigh 52 lbs!

The advances in manufacturing techniques in resistance-wire garments have been paralleled by recent advances in high energy battery developments. Electro-chemical primary and secondary cells have been developed that will provide power supplies for supplemental heating devices. The increase in the power/weight ratio of both silver-zinc and silver cadmium batteries makes both battery types usable. Silver zinc batteries provide from 40-80 watthours (whr) per pound, whereas the silver cadmium batteries provide 30-60 watthours (whr) per pound. The cost of these batteries is likewise high, i.e., approximately $1/whr for silver zinc and $1.3/whr for silver cadmium.

Sea water activated batteries of the silver chloride/magnesium type offer the highest power factor for this battery type. With such a system, it would be possible to provide 40 watts of heat to boots and gloves for 6 hours at a battery weight of 7 lbs. The electric resistance-wire and battery system is an immediately available, workable system and offers the greatest advantages, i.e., variable heat control, both as to amount and area supplied, a thermostatically controlled on/off cycle, and an evenly distributed supply of heat. One experimental Army Aretic glove and boot system (Figure 5) is thermostatically controlled and supplies 10-20 W to each glove and each boot. This assembly has been tested with a ¼ inch neoprene wetsuit and protected the hands and feet effectively, more than doubling the voluntary immersion time of subjects in 40° F water. This thermal protective system when used with 350 whr AgCl-Mg sea water batteries would weigh a total of 22 lbs., and would protect the body and extremities for over 4 hours in 40 F water.

Recent advances in thermionics, thermoelectric generators, catalytic fuel cells and exothermic chemical reactions offer a wide range of selection for heat generation which potentially may be developed into useful systems for replacement heating of immersed survivors, in addition to the resistance-wire heating system used with high power/density bateries. Isotopic power generators provide the highest power to weight ratio of any system. Alpha emitting isotopes require the least shielding. Polonium-210 has a high power density, 140 thermal watts/gm. If the fuels alone are considered, it would require only 10 gms. of Polonium to provide enough heat to keep an immersed human warm without any added external insulation! However, Polonium has a half-life of 138 days which limits its shelf life. Although the present cost is about $800.00/watt, future development should decrease the cost to about $25.00/watt. Polonium also has decay emissions which introduce serious shielding problems. A comparative tabulation of the various isotopic power generators is shown in Table III.[4] When the cost and the weight of the shielding are considered, these isotopic power units seem to have less value for present survival systems.

TABLE III RADIOISOTOPES FOR THERMAL POWER SOURCES

Radioisotope Fuel	Half-life (years)	Initial Power Density (watts/gram)	Cost $/W	Major Radiations
Strontium 90	28	0.93	19,50	Beta, a few gammas
Cesium 137	30	0.39	41,00	Beta a few gammas
Cerium 144	0.78	25.0	1.06	Beta a few gammas
Promethium 147	2.5	0.36	91,00	Beta a few gammas
Polonium 210	0.38	141.0	20.00	Alpha
Plutonium 238	89	0.55	1,000.00	Alpha
Curium 242	0.45	121.0	17.00	Alpha Neutrons
Curium 244	18	2.8	357.00	Alpha + Neutrons

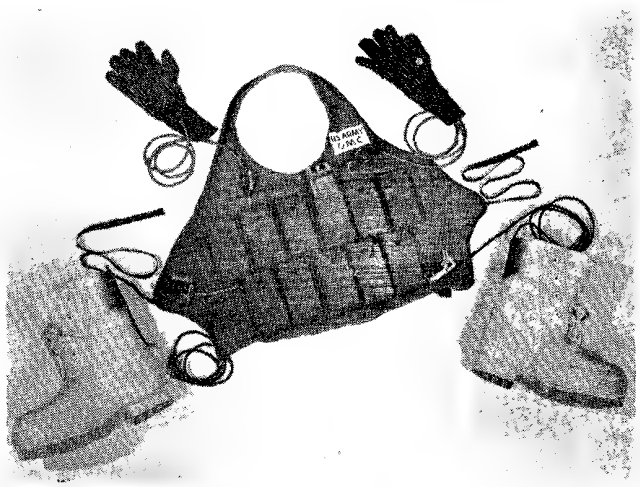


Fig. 5 U. S. Army electrically heated gloves and boots with battery pack.

Heating systems employing the flameless surface combustion of hydrocarbons in the presence of specific catalysts are also efficient heat sources (13 whr/gm). Hand warmers for hunters are of this type and are marketed.* The temperature of the combustion varies from 316 C upward so that this system could not be used for direct heating, but would have to use an intermediary heat transfer system.

A new type of catalytic heating device which utilizes the combustion of hydrogen in the presence of a proprietary catalyst** at a temperature of 38 C offers

*Therm-X and Whamo.

**Ethyl Corporation Research Laboratory, Detroit, Michigan.

TABLE IV. COMPARISON OF VARIOUS HEAT GENERATING SYSTEMS

Thermal System	Reactants	Product	Power or Energy Density	Estimated Wt of 100 W/Hr Power Unit in Kg	Duration of Power Cycle	Stage of Development	Estimate Cost of Power Unit in $ (Exhaling Development Costs)
Primary Battery	$AgCl_2$ + Sea-water	Electricity	.1-.2 whr/gm*	3.0	5 hrs.	Evaluation	$ 300.00+
				3.0	5 hrs.	Evaluation	250.00+
Secondary Battery	Silver-Zinc	Electricity	.1-.2 whr/gm	4.0	5 hrs.	Evaluation	400.00+
	Silver-Cadmium	Electricity	.08-.16 whr/gm*	3.0	89 yrs.	Development	250,000.00+
Radio Isotope	Plutonium-238	Heat	.55 W/gm**	10.0	0.4 yrs.	Research	20,000.00+
Radio Isotope	Polonium 210	Heat	141.0 W/gm**				
Thermo-Chemical	$Mg + H_2O \xrightarrow{FE} MgO + H_2 +$ [H]	Heat	3.8 whr/gm*	2.0	5 hrs.	Development	5.00++
Fuel Cell	$NaAlH_2 + 2H\text{-}O \rightarrow NaAlO_2 + 4H_2$ $2H_2 + O_2 \rightarrow H_2O +$ [H]	Heat	4.7 whr/gm*	3.0	5 hrs.	Development	15.00++
Wet Suit	Unicellular Foamed Neoprene	Insulation	.05 W/gm*	4.0		IN USE	25.00
Food	$CHO + O_2 \rightarrow CO_2 + H_2O$ [H]	Heat	4.6 whr/gm	0.5	5-10 hrs.	IN USE	0.50

*Measured
**Theoretical
+Requires use of Resistance Heating Suit Wt = 2Kg
++Requires use of water conditioned suit Wt = 3Kg

promise. The theoretical efficiency of such a thermal generator would be high with an energy density of 8 whr/gm. In this system, hydrogen would be generated by reacting sodium aluminum hydride with water according to the equation:

$$Na\ AlH_4 + 2H_2O \rightarrow Na\ AlO_2 + 4H_2$$
$$2H_2 + O_2 \rightarrow 2H_2O\ [H]$$

Since both air and water are available in excess in a surface survival situation, this chemical reaction has certain advantages. However, the mixture of oxygen and hydrogen must be carefully controlled to limit the O_2/H_2 ratio to more than 21/1 by volume to prevent the mixture being explosive. The practical energy of this system should be in the order of 10 pounds of equipment to provide 350 thermal watts for four hours. This system is currently under development for the U. S. Navy.*

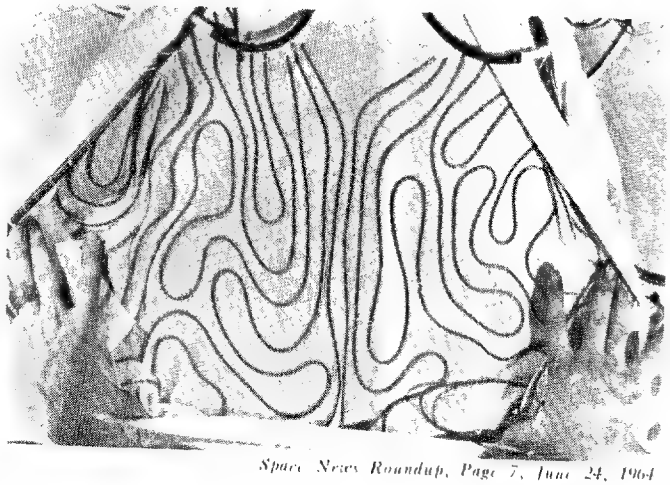
Thermochemical systems such as the combination of magnesium and water in the presence of iron also give a relatively high theoretical energy, on the order of 1.5 KWH per pound (4.0 whr/gm). Such a unit would have an indefinite shelf life and would cost relatively little, perhaps 10c per watt. The basic ingredients are readily available and a simple and suitable heat generator could easily be provided. Unfortunately, this is the type of reaction that is very difficult to control once it has been initiated although the gas that is generated could possibly be utilized to quench the reaction. Similar exothermic chemical reactions could be employed, such as the heat generation provided by the hydrolysis of sodium. However, these types of reactions could not be used to heat the body directly. A summary of the various power conversion systems is set out in Table IV, where it is shown that there are several conversion systems available which would provide sufficient heat to significantly prolong survival and operating times during immersion in cold water if the heat could be properly distributed. Recent developments of a liquid distribution system along the lines recommended by Siple[22] show considerable promise. The principle of the "water conditioned" suit for heating and cooling the body is essentially simple, and utilizes the high specific heat of water (or other high specific heat liquid) to distribute heat to or transfer heat from the various areas of the body as required. Pioneer work on this type of suit has been carried out at the Royal Aircraft Establishment, Farnborough, England,[23] and is being pursued at the Manned Spacecraft Center, NASA, Houston.[24,25]

In the model under development for NASA by Dr. J. Billingham (Figures 6 and 7), thin (2mm) plastic water pipes are incorporated into Brynje type (fishnet) undergarments so as to have heat exchange tubes covering the skin about 2 cm apart. By taking advantage of the normal skin temperature gradient from the central body toward the extremities, cooling water is pumped over the extremities toward the central body to provide a progressive heat transfer gradient. Heating is accomplished by pumping the heated water first over the trunk and then to the extremities. Dr. Billingham tested one of these suits under a 3/16-inch unicellular foamed diver's wetsuit. He was immersed in 4°C water for 70 minutes and maintained his body temperature by using an inlet water temperature of 45°C and a mean flow of 3.8 liters of water per hour.

*Aerospace Crew Equipment Laboratory, Naval Air Engineering Center, Philadelphia, Pennsylvania.

Space News Roundup, Page 6, August 5, 1964.

Fig. 6. Water cooled garment.



Space News Roundup, Page 7, June 24, 1964

Fig. 7. Plastic water pipes sewn into the material of long underwear.

This suit uses a miniature electric pump which, with its battery and gearbox, weighs only 340 gms. The suit itself weighs only 2 kilograms.

The water conditioned suit holds considerable promise for use not only for supplying heat to immersed personnel but for cooling flight personnel as well. Because the liquid is incompressible and the tubes are relatively rigid, the pressure drop in the tubing is not affected by immersion as occurs in the air conditioned suit. Reference to the power conversion Table IV shows that the most efficient systems supply only heat. The chemical heating system has a high efficiency and would provide an excellent heat exchanger for use with the water conditioned suit. An isotopic power conversion unit would likewise by adaptable for use with the water conditioned suit.

In order to meet present needs for thermal protective anti-immersion clothing, it therefore seems advantageous to incorporate unicellular foamed neoprene with supplemental resistance heating systems into anti-exposure garments. The neoprene foamed suits are desirable as protective garments because of the following advantages: (1) they provide effective, reliable, and adequate insulation for use in a cold, wet environment; (2) they provide positive buoyancy at all times; (3) they provide mechanical protection against external moving objects; and, (4) they are relatively inexpensive. An electric resistance-wire supplementary heating system consisting of boots and gloves, powered by a silver chloride-magnesium sea water battery would provide adequate protection for an operation immersion of useful duration when used with a 3/16-inch unicellular neoprene wetsuit.

For future development, the water conditioned suit might be exploited for use beneath the unicellular foamed outer garment. The development of low temperature oxidation and thermochemical cells should provide a significant improvement over the efficiency and power density of the battery systems. The development of such a heating system should be of use not only by aircrew, but also by divers, underwater swimmers, reconnaissance teams, and the Army Corps of Engineers.

REFERENCES

1. Carlson, L. D., Hsieh, A. C. L., Fullington, F., and Elsner, R. W.: Immersion in Cold Water and Body Tissue Insulation. *J. Aviat. Med.* 29:145-152, 1958.
2. Pugh, L. G. C., and Edholm, O. G.: Physiology of Channel Swimmers. *Lancet* 2:761-768, 1955.
3. McQueen, J. D.: Effects of Cold on the Nervous System. In The Physiology of Induced Hypothermia. Edited by R. D. Dripps, NAS-NRC Publ. 451, Washington, 1956, pp. 243-60.
4. Virtue, R. W.: Hypothermic Anesthesia. Springfield, Ill.: Thomas, 1955.
5. Provins, K. A., and Clarke, R. S. J.: The Effect of Cold on Manual Performance. *J. Occupational Med.* 2:169-175, 1960.
6. Beckman, E. L.: Unpublished data.
7. Beckman, E. L.: Thermal Protection During Immersion in Cold Water. Pp. 247-266, Proceedings of the Second Symposium on Underwater Physiology. Publ. 1181, NAS-NRC, 1963, Washington, D. C.
8. Morehouse, L. E., and Miller, A. T.: Physiology of Exercise. Pp. 238-239, C. V. Mosby Co., 2nd edition, 1963.
9. Hunt, H., Reeves, E., and Beckman, E. L.: An Experiment in Maintaining Homeostasis in a Long Distance Underwater Swimmer. MR005.13-4001.06 Report No. 2, Naval Medical Research Institute, Bethesda, Maryland, 23 July 1964.
10. Beckman, E. L., and Reeves, E.: Physiological Implications as to Survival During Immersion in 75° F Water. *Aerospace Med.* (in press).
11. Guyton, A. C.: Specific Dynamic Action of Food. Page 923 in Textbook of Medical Physiology, W. B. Saunders Co., Philadelphia, 2nd ed., 1961.
12. Belding, J. S.: Protection Against Dry Cold. Physiology of Heat Regulation and the Sciences of Clothing. Pp. 351-367, edited by L. H. Newburgh, W. B. Saunders Co., Philadelphia, 1949.
13. Van Dilla, M., Day, R., and Siple, P. A.: Special Problems of Hands. Ibid. Pp. 374-387.
14. Goldman, R. F., Beckman, E. L., Reeves, E., and Breckenridge, J. R.: Protection Against Water Immersion: The "Dry Suit" versus the "Wetsuit" Concept. ARIEM. Prepublication Data.
15. De Forest, R., and Beckman, E. L.: Some Contraindications to Use of Life Jacket for Survival. *Arch. of Env. Health* 4:58, 1962.

VOLUME 35
NUMBER 9
SEPTEMBER 1964

Aerospace Medicine

FORMERLY THE JOURNAL OF AVIATION MEDICINE
FOUNDED BY LOUIS H. BAUER, M.D.
Official Publication of the Aerospace Medical Association

Field Evaluation of Full Pressure Suits in Arctic Environments

CAPTAIN JAMES H. VEGHTE, USAF

ABSTRACT

Thermal responses of six subjects wearing full pressure suits were monitored for several days under Arctic field conditions. In laboratory experiments, heat loss from clothed subjects was measured with an infrared radiometer, and moisture accumulation within the clothing determined during exercise. In temperatures of − 16° F., five of the six subjects with no survival equipment reached tolerance limits (skin temperature of 35° F.) before 15 hours had elapsed. Termination of the experiment was always because of foot temperatures. Heat loss for these subjects varied from 0.6 to 20.6 Kcal/m² hr. With survival equipment, subjects tolerated ambient temperatures that varied from − 24° to 25° F. for 72 hours. Radiometric thermograms of the pressure garments indicated gloves, zippers, and face were high heat loss areas. Over 600 g of sweat were retained in closed pressure suits during mild exercise at − 10° F. When the suit was partially opened, there was a significant reduction of this retained moisture. These data show the critical need for extremity protection, shelter, and ventilation of the pressure garments in dry cold environments.

A FIELD EVALUATION of Air Force full pressure suits was conducted by personnel of the Arctic Aeromedical Laboratory during the past two winters near Fairbanks, Alaska. This evaluation was requested by an operational command to resolve conflicting results of previous field studies. The experimental program was designed to determine tolerance limits of aircrew members wearing this clothing in a dry cold environment with and without ancillary survival equipment. Experiments that required elaborate instrumentation or control of environmental temperature were conducted concurrently in the laboratory.

From the Aerospace Medical Research Laboratories, Aerospace Medical Division, AFSC, Wright-Patterson AFB, Ohio.

Presented at the Aerospace Medical Association Meeting in Miami, Florida, May 12, 1964.

METHODS

The experimental program was divided into three test series. In the first two series, six test subjects were to live in the field for a maximum of three days. In the first test series, the subjects did not have any survival equipment or food, while in the second series, subjects did have survival equipment identical to that carried by fighter aircraft flying in the Arctic. This equipment included down survival clothing and food. In each test series, the temperature varied from − 24° to 20°. F. In addition, different survival techniques and survival shelters were evaluated. Four of the six test subjects were comparatively inexperienced in survival techniques but had been exposed periodically to low temperatures. The other two subjects were Arctic survival instructors.

The basic clothing assemblies were identical in both tests: thermistor underwear (to monitor 17 skin temperatures and rectal temperature), waffleweave underwear, A/P 22 S-2 or A/P 22 S-3 pressure garments, 2 pairs of wool socks and quick-don alert boots. Temperature measurements of each subject were taken every 4 hours during the day and every hour during the night unless there was a possibility of impending tolerance. Tolerance for these experiments were defined as any skin temperature of 35° F or a rectal temperature of 95° F. If tolerance conditions were approached, the subject's temperatures were monitored every 15 minutes.

The third test series was conducted at the laboratory to determine: the moisture retained within the various articles of clothing during moderate exercise and areas of high heat loss from the pressure suit determined with an infrared radiometer.

RESULTS AND DISCUSSION

Test Series 1 (Without survival equipment):—Temperatures during the first test varied from a low of

$-16°$ F the first night to a high of 10° F the second day. Five of the six subjects reached tolerance limits during the first night. Their exposure times were 7, 10, 14, 14, and 14.5 hours. In each case termination of the experiment was due to extremity temperatures (Fig. 1). Four of the five subjects replaced their com-

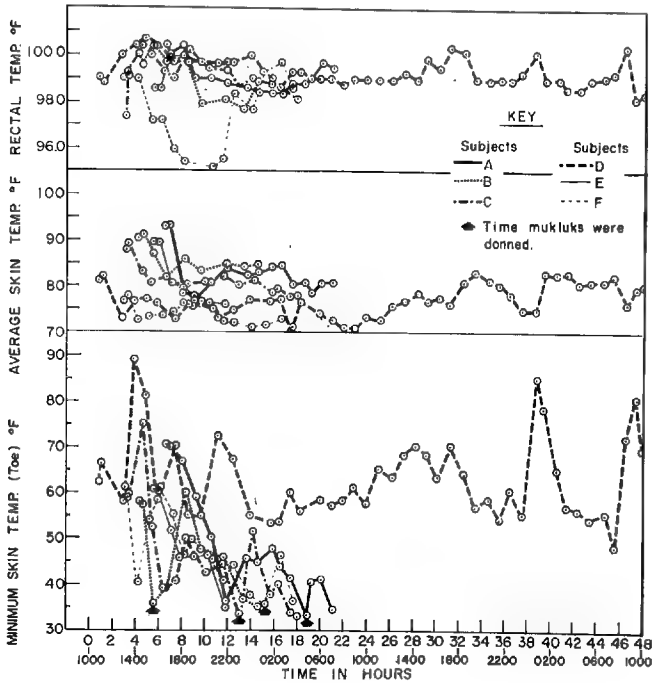


Fig. 1. Skin and core temperature response to experimental conditions (Test series No. 1).

bat boots with the arctic mukluk assembly when the temperature of their toes reached 35° F. Despite the additional insulation provided by the mukluks (1.75 clo), their cold feet did not rewarm sufficiently and they were withdrawn from the field. Apparently, once the vasculature of the extremities has constricted, increased insulation by itself is not sufficient to reestablish normal blood flow. The average skin and rectal temperatures are within the comfort range. The calculated heat losses for the five subjects, who reached tolerance, were 20.6, 10.8, 9.4, 7.3, 0.6 Kcal/m^2 hr. These values indicate the subjects were in a state of moderate cold strain. The extremities were the only problem. Subjective comments were particularly critical of pressure gloves, since hands became extremely cold during rest and the discomfort caused by the helmet. With the helmet on, the head was warm, but at these temperatures the subjects preferred a toque or pile cap. When the helmet was removed, excessive heat loss occurs through the open neck of the suit. This heat loss may be reduced by stuffing parachute material around the neck. In one instance, accumulated moisture in the helmet's neck ring froze, and the subject had difficulty in removing the helmet. All subjects complained about the cold along the zipper across the back of the suit.

One subject, an arctic survival instructor, was able to tolerate the temperature stress for 48 hours, when the experiment was terminated by the monitors. He kept his feet warm by maintaining a continuous fire.

Test Series 2 (With ancillary survival equipment):—The temperature varied from 8° to 25° F during this test. None of the subjects reached tolerance because of the moderate temperatures, and again the experiment was terminated by the monitors after 48 hours. The temperature of the toes was variable because of the warm weather and additional insulation on the feet (down mukluks). The average skin and rectal temperatures show typical diurnal cycles and all values are within the comfort range (Fig. 2). Changes in stored

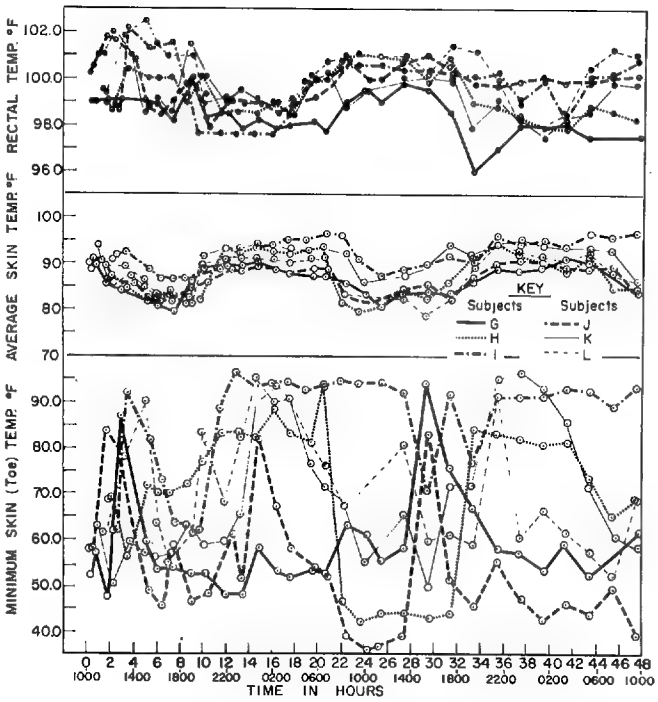


Fig. 2. Skin and core temperature response to experimental conditions (Test series No. 2).

body heat for these subjects were: -2.2, -1.8, -1.7, -0.9, -0.3 and $+2.2$ Kcal/m^2 hr.

Several subjects completely removed the pressure suit and were comfortable in only the down survival clothing. The down clothing proved difficult to dry, however, once it became wet. Also, sparks from fires melted holes in the outer covering of the down clothing, and snags ripped several parkas so badly that they were in tatters. Extreme caution and care is required to keep the down clothing functional in prolonged survival situations. Once removed, a cold soaked pressure suit (exposed to a temperature of $-20°$ F for one hour) can be donned in 15 minutes by an experienced subject. One subject experienced mild snow blindness, and based on past experiences, snow goggles must be worn continuously during the spring in the Arctic.

Snow houses have proven to be far superior to any other shelter in the Arctic.[1, 3] When temperatures varied from $-15°$ to $-24°$ F, subjects wearing down-filled clothing survived for 72 hours in snow houses, while the subjects wearing just the full pressure suits aborted the experiment because of cold extremities.[2]

Test Series 3. A. Moisture retention in the pressure suit and down clothing:—In laboratory experiments,

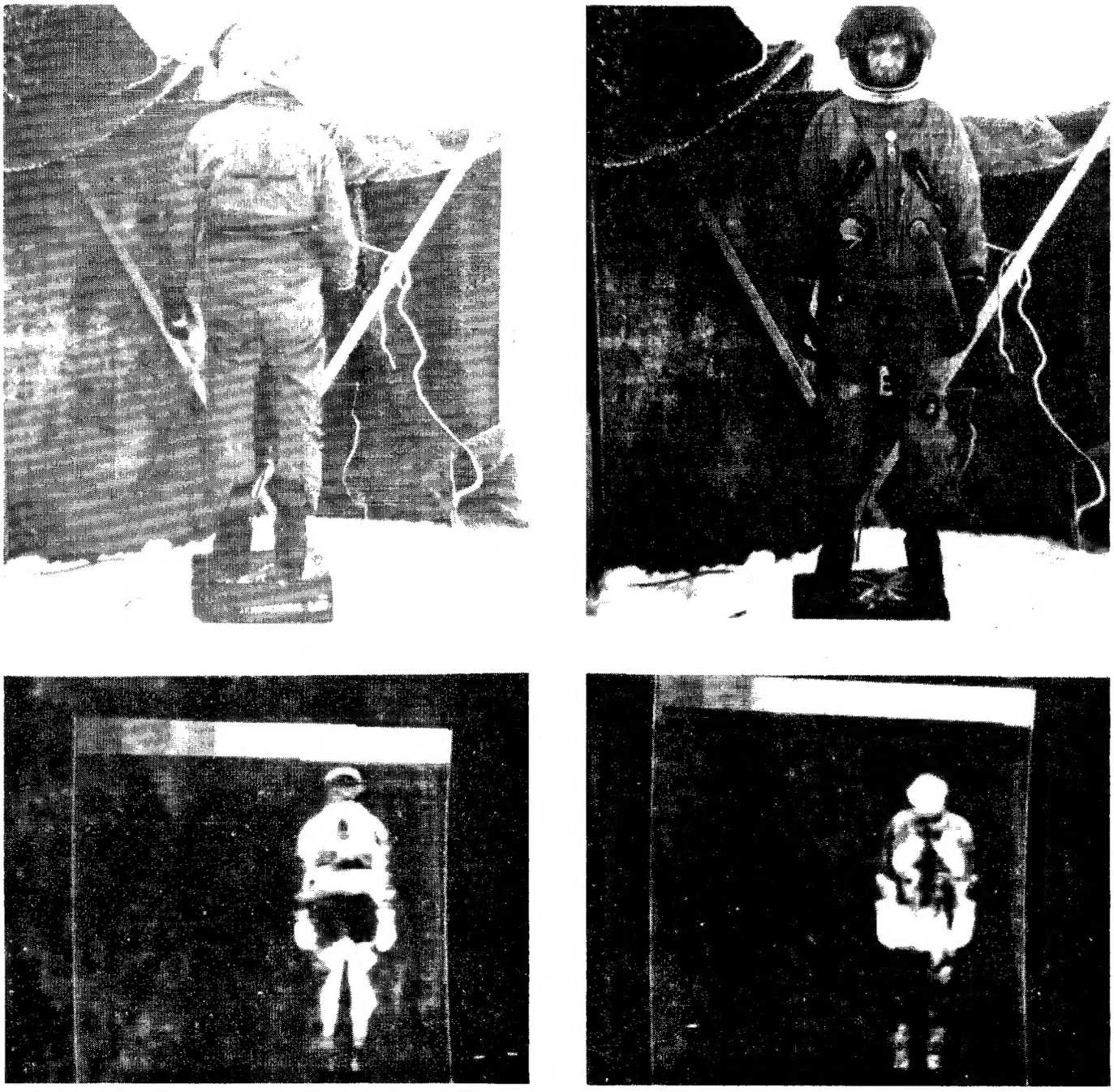


Fig. 5. Thermograms of the subject wearing the A/P 22 S-2 full pressure garment. The areas of high heat loss are the white regions and the colder areas are dark.

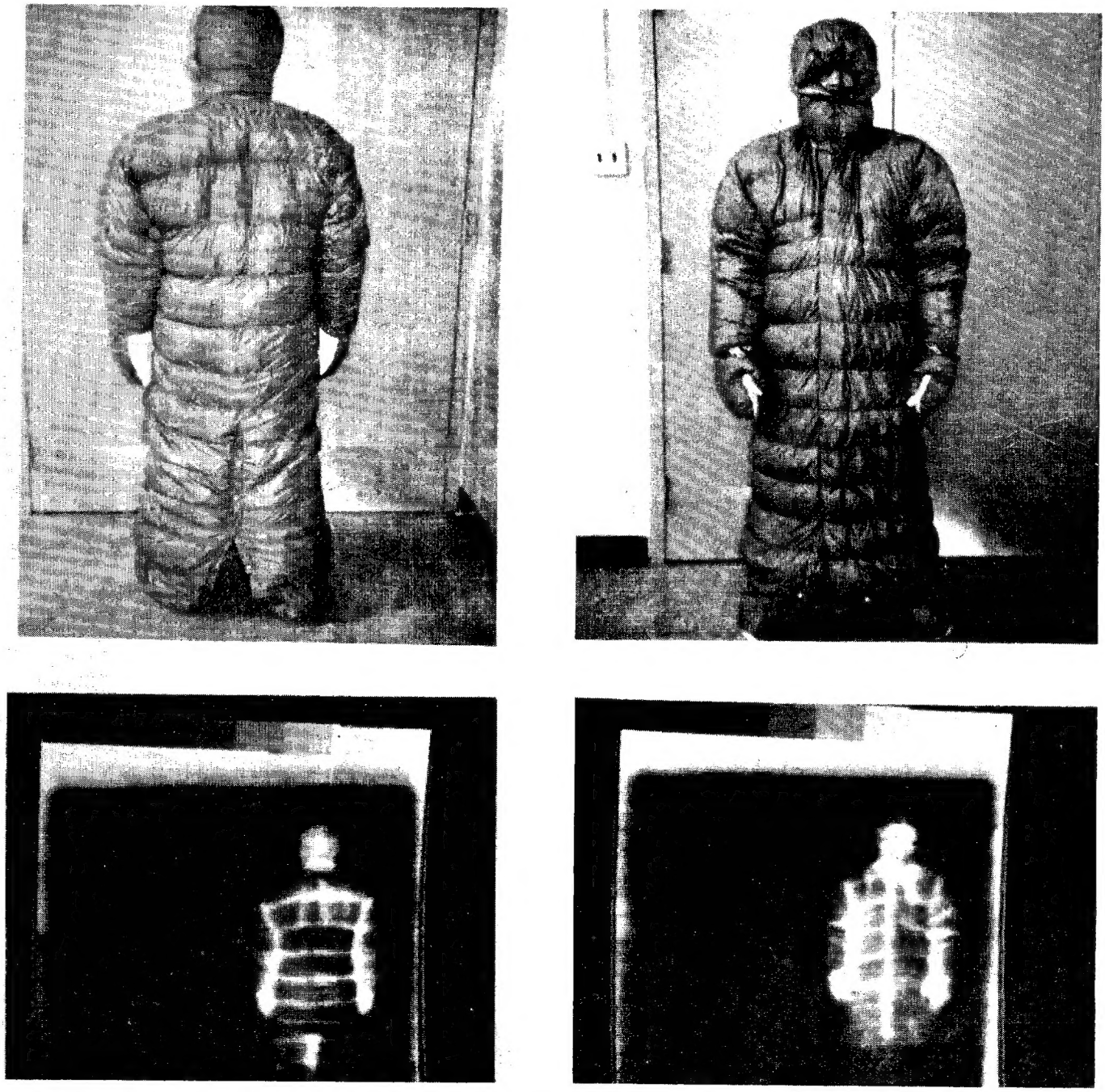


Fig. 6. Thermograms of the subject wearing the down survival clothing.

subjects walked for 1 hour on a treadmill set up at miles per hour with a 0° slope. The various clothing components were weighed before and after the experiment to determine the amount of moisture accumulation in the clothing. With the pressure garment fully closed, there is a high sweat rate during mild exercise (Fig. 3). Most of this moisture is retained in the

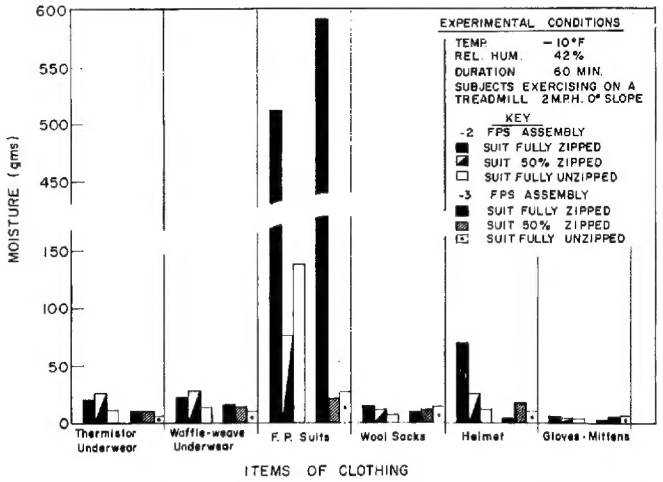


Fig. 3. Amount of moisture retained in various clothing items of the full pressure assemblies.

pressure suit itself. With the exception of the helmet, the other clothing components picked up little moisture. With the suit 50 per cent unzipped, there was considerable reduction in moisture within the pressure shell.

In other experiments, the same exercise regime as above was followed, but the down clothing was worn either by itself or over the pressure suit. With the down clothing worn over the pressure garment, there is an increase in moisture in the underlying clothing apparently because of the increased impermeability of the total clothing assembly (Fig. 4). The pressure suit was completely unzipped which accounts for the low moisture retention in the pressure suit. Low moisture retention in the down clothing, when worn without the

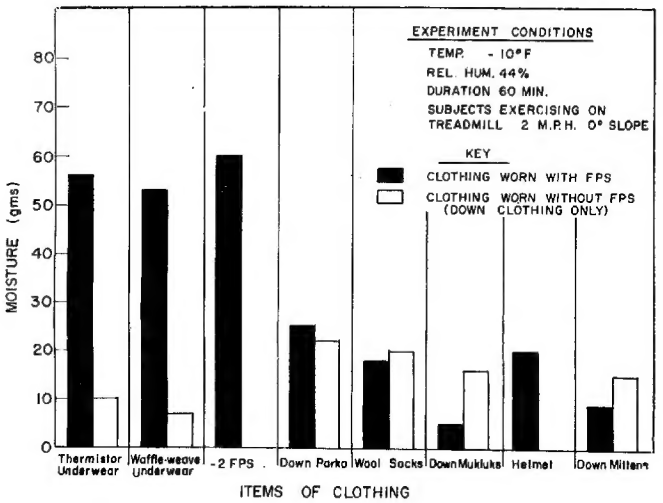


Fig. 4. Comparison of moisture retained in down clothing worn over the FPS and without the FPS.

pressure suit underneath, is encouraging but the down clothing must be dried out daily to prevent accumulation of moisture which over a period of several days reduces the effective insulation of the clothing. In the second test series, there was an accumulation of 170 g in the down clothing by the end of the experiment (48 hours). The mukluks were particularly wet. Preliminary studies show only 400 g of water uniformly distributed throughout the down clothing is necessary to affect insulative values to such an extent as to produce noticeable changes in skin and rectal temperatures.

B. *Areas of Heat Loss from the Pressure Suit:*— Twenty-three experiments were conducted to determine the surface temperatures of the pressure suits with the infrared radiometer. Temperatures varied from −10° to 10° F during these experiments. The radiometer's pictures (thermograms) were taken after the subjects equilibrated for 30 to 40 minutes to the outside temperatures (Fig. 5). In the thermograms, the warmer areas are lighter, and the colder areas are darker. This figure shows the clothing worn at the top and the thermograms taken with the radiometer at the bottom. The areas of high heat loss are the pressure gloves, the zipper in the groin, the chest and back zipper, the face, and the back of the thighs.

When only the down clothing is worn, considerable heat is lost from the face and hands (Fig. 6). There is a poor neck and front closure in these garments. The snaps should be replaced with velco or another continuous fastener. The heat loss through the seams of this clothing is because of poor clothing construction that should be corrected.

SUMMARY

Extremity temperatures are critical during moderate cold stress and must be adequately protected. There is no appreciable difference in tolerance limits of subjects wearing the two types of pressure garments. With no survival equipment at −16° F, five of six subjects reached tolerance by 15 hours. With survival equipment, tolerance was increased to 72 hours. Without survival equipment, mukluks can be improvised from parachute cloth, and foot insulation can be increased by wearing extra socks over the boots. The pressure suit should be partially opened while making a shelter or during other activity. Shelter and fire are essential. If down clothing is available, the pressure suit should be removed and the down clothing put on. A snow shelter must be constructed at once—even at night.

REFERENCES

1. Milan, F. A.: An evaluation of winter survival shelters used by the U. S. Air Force in Alaska. TR 60-8. Arctic Aeromedical Laboratory, Ft. Wainwright, Alaska. January 1961.
2. Milan, F. A.: Personal communication. Arctic Aeromedical Laboratory, Ft. Wainwright, Alaska. March 1964.
3. Vegiite, J. H., White, F. E., Millard, W. W., Schumann, J. R., and Kennedy, C. F.: Evaluation of the KC-135 and U-2 bailout survival kit. TN 63-4. Arctic Aeromedical Laboratory, Ft. Wainwright, Alaska. February 1963.

The Hematologic Effects of Microwave Exposure

S. M. Michaelson, D.V.M., R. A. E. Thompson, M.T., M.Y. El Tamami, M.D.,
H. S. Seth, M.D., and J. W. Howland, Ph.D., M.D.

ABSTRACT

Reports in the past have indicated non specific hematologic changes among persons occupationally exposed to radar. Most of the hematologic studies on animals exposed to microwaves have been limited to observations in rodents. Systematic study of the effects of microwaves in the dog is relatively rare although this animal has a hematologic system much more comparable to man than do rodents. Whole body exposure of normal dogs to microwaves results in leukocyte changes which can be related to frequency, field intensity, and duration of exposure. A marked decrease in lymphocytes and eosinophils occurs after six hours of 100 mw/cm.^{2}, 2800 Mcycles/sec. (pulsed) microwave exposure with a mean rectal temperature increase of 1.8 F. Neutrophils are slightly increased at 24 hours while eosinophils and lymphocytes have returned to normal levels at this time. After two hours of exposure to 165 mw/cm.^{2} with a resultant 3 F rise in rectal temperature there is a slight decrease of all white cells and a definite hemoconcentration. Eosinopenia is still evident twenty-four hours after exposure. Hematologic changes are more marked after three hours exposure to 165 mw/cm.^{2} Cr^{51}, and Fe^{59} studies indicate alteration of red blood cell life span and bone marrow function at these exposure levels. General leukocytic changes are more apparent after 1280 Mcycles/sec. pulsed and 200 Mcycles/sec. continuous microwave exposure. Simultaneous x-irradiation and microwave exposure results in accelerated recovery of the ionizing radiation induced neutropenia and prolongation of the lymphocytopenia. The results of these studies are indicative of hypothalmic and/or adrenal stimulation (stress effect) of microwave exposure and the biologic interaction of microwave and ionizing radiation energies. Alterations in ferrokinetics which are related to duration of exposure indicate effect of microwaves on the bone marrow.

INCREASED INTEREST in the biologic effects of exposure to microwaves has developed during the past twenty years. Concern as to possible hazards to man has prompted studies and analysis of data from both animals and humans exposed to this form of energy.

Although reference has been made in the literature to hematologic changes in man and experimental animals exposed to microwaves, a detailed analysis has not been made. Most of the reports of hematologic changes in animals exposed to microwaves are concerned with observations on rodents. The dog, because of his size and known responses to experimental manipulation is well suited for investigation of the hematologic effects of microwave exposure.

The following observations are presented to provide information on the hematologic changes in the dog induced by microwave exposure.

MATERIALS AND METHODS

Adult mongrel dogs of either sex 1-5 years of age were exposed to microwaves at power levels of 50 mw/cm.^{2}, 100 mw/cm.^{2} and 165 mw/cm.^{2}. The microwave sources used were a 2800 Mcycles/sec.(AN/FPS-6), a 1280 Mcycles/sec.(AN/FPS-8) pulsed radar units or a 200 Mcycles/sec. continuous wave transmitter.

Unanaesthetized dogs were exposed in a Plexiglas cage which permitted freedom of movement. The cage was situated in an anechoic chamber $7 \times 7 \times 15$ ft. lined with commercial microwave absorbing material. The dog's body temperature was monitored with an electronic thermometer with the use of a thermister probe shielded with Plexiglas and fixed in the rectum. Blood for hematologic examination was obtained by a

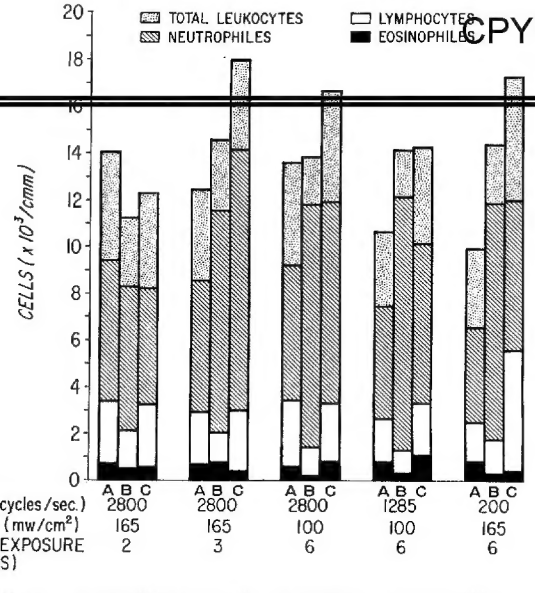


Fig. 1. The effect of microwaves on leukocytes.

From the Department of Radiation Biology, University of Rochester School of Medicine and Dentistry, Rochester, New York.

This paper is based on work performed at the University of Rochester, Rochester, New York and Griffiss Air Force Base under Contract #AF 30(602)-1813 with USAF.

Opinions expressed in this paper are those of the authors and do not represent the official views of the U.S. Air Force.

This certifies that the experiments described in this paper were conducted according to the "Rules Regarding Animal Care" as established by the American Medical Association.

The advice of Professor Herbert Mermagen and technical assistance of Joe Parmentier and Theodore Elliott are gratefully acknowledged.